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THE EFFECT OF COMBAT BOOT INSERTS ON COMFORT, INJURY FREQUENCY AND PERFORMANCE

Human Performance Laboratory
Faculty of Kinesiology

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By

Anne Hau, Darren J. Stefanyshyn, Benno M. Nigg
Human Performance Lab
Faculty of Kinesiology
The University of Calgary
2500 University Drive N.W.
Calgary, Alberta
Canada T2N 1N4

Project Manager:
Stefanyshyn, Darren J.
Phone: (403) 220-8637
Fax: (403) 284-3553
Email: darren@kin.ucalgary.ca

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Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West
Downsview, Ontario, Canada
M3M 3B9

DCIEM Scientific Authority:
Walter Dyck
(416) 635-2192

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EXECUTIVE SUMMARY

Army personnel are often required to spend significant amounts of time executing their tasks while wearing the same footwear. The importance of appropriate footwear for this population is obvious. However, what is considered appropriate footwear for one individual may not be appropriate for another individual. The fact that the majority of the military population is issued identical footwear would suggest that at least some individuals do not have appropriate footwear. Unfortunately, the guidelines for determining an appropriate boot for an individual are not well determined. Ultimately, these guidelines should be used to prescribe appropriate footwear to specific individuals.

As a first step in understanding these guidelines, an initial study was performed to determine the anthropometric and sensory factors which may predict the short term reaction of the foot to a set of selected shoe-insert constructions. The study found that changes in insert properties elicited substantial changes in comfort ratings of a group of 106 university students. The comfort ratings depended on specific insert characteristics as well as lower extremity characteristics such as foot sensitivity and leg alignment. This current study was the second step in understanding these guidelines and was performed as a follow up study to identify similar characteristics using a military population and to determine the influence of inserts on injuries and performance.

The purposes of this study were to determine:

a) **lower extremity anthropometric and sensory factors which predict the comfort of selected boot-insert constructions in a military population and**
b) **the influence of boot inserts on lower extremity injuries and performance of a military population executing military tasks.**

A total of 206 military personnel from the Edmonton Garrison volunteered for this study. The subjects were split into two groups of 103 subjects, an insert group and a control group. Foot shape, leg characteristics, and foot sensitivity measurements were taken from all 206 subjects. Subjects in the insert group chose the most comfortable insert from a set of six boot inserts different in shape and material. The foot measurements and the comfort assessment were conducted at the PPCLI unit in Edmonton, Alberta. Subjects then wore the selected inserts for a period of four months. During these four months, subjects in both groups (insert group and control group) reported any pain or injuries they experienced. At the end of four months, eight subjects from the insert group performed oxygen consumption tests with and without their chosen inserts in their combat boots. The oxygen consumption tests were performed at the exercise physiology laboratory at the University of Alberta, Edmonton.

Comfort results

All insert conditions led to a significant increase in comfort rating compared to the issued insert condition. Only 4 of 103 subjects rated the issued insert condition as the most comfortable. The inserts with the highest comfort ratings were composed of soft material in the heel region and soft and elastic material in the forefoot region. In contrast, the least comfortable inserts were made of hard material in the heel and forefoot region and/or viscous material in the forefoot region. These results are similar to the results found in the initial study. Only four different

inserts were necessary to substantially increase the comfort rating (greater than two comfort points) for ninety percent of the individuals. Thus, it appears that only a small number of inserts are necessary to satisfy a large portion of the military population.

Specific insert results

It became apparent that foot sensitivity and foot and leg geometry and alignment are independent factors for footwear comfort:

- Subjects with a low foot arch preferred an insert that gives way but also provides a certain amount of support and, therefore, liked the viscous insert and hard insert.
- A high foot arch provides support in itself. Thus, subjects with a high foot arch preferred a material that is soft, i.e. the soft insert and the elastic insert.

- Highly sensitive subjects do not need a high input signal. They preferred an insert that filters the input signal, i.e. the viscous insert and the soft insert.
- Less sensitive subjects may not be able to obtain sufficient information from the filtered impact input signal and, therefore, preferred the elastic insert.

In general, subjects that have a poor aligned skeleton or a low arch prefer viscous inserts whereas elastic inserts are more comfortable for subjects with a well aligned skeleton and a high arch.

Injury results

Overall, 40.5% of the subjects who provided injury data had an injury. Injuries were defined as any pain, hot spots/blisters, and stress fractures. There were no significant differences in the overall number of injuries between the insert and the control group. However, the number of subjects with pain and stress fractures were lower for the insert compared to the control group. There was a significant decrease in pain and stress fractures in the feet of the subjects using inserts. Thus, it appears that inserts may have a positive effect in reducing more severe injuries in military personnel. The inserts did cause an increase in the number of blisters/hot spots encountered by the subjects. The particular inserts used appeared to have a rather high friction coefficient which could have lead to the increased number of blisters. Thus the surface characteristics of any inserts should be carefully considered before implemented.

Performance Results

There were no significant differences in the oxygen consumption (energy expenditure) of subjects when marching with the test inserts or with the issued inserts. Previous studies have shown increased oxygen consumption with inserts, primarily due to the additional energy required to accelerate the added mass. This was not found in this study, and it may be that the positive effects (e.g. improved comfort) of the insert condition offset the negative effect of the added mass. However, the information with respect to performance should be interpreted with caution as this data is based on a limited sample size of only eight subjects.

Speculation-Concepts

It is speculated that the majority of the military population can be appropriately served with only four different types of inserts. In general these inserts should be soft and have an elastic forefoot. Options of a low or high arch, a flat or spherical heel and a viscous or elastic heel region should also be available.

The speculation that subjects with a poor alignment of the skeleton (heel, subtalar joint, tibial torsion, Q-angle) are best served with a soft and viscous insert was supported. Subjects with poor skeletal alignment do not want anything resisting their foot movement and, thus, prefer soft and viscous materials.

Similar to the results that were found previously, subjects that are highly sensitive prefer soft and viscous materials. Subjects that have a low sensitivity prefer hard elastic materials. These speculations can be supported by functional considerations. Subjects who are highly sensitive do not need extra input signals. However, subjects who are not highly sensitive may need strong input signals produced by the hard elastic materials.

It is speculated that the use of inserts will result in reduced lower extremity injuries. It will be important to have appropriate surface characteristics to avoid blisters, but if correctly constructed, the potential to reduce more severe injuries exists. The use of inserts is also speculated to have little or no effect on performance.

INTRODUCTION

It has been shown that footwear can have an influence on the energy expenditure of an athlete as well as on the frequency of overuse injuries (Frederick et al., 1983; O'Toole et al., 1989). The majority of these studies have been performed using athletic footwear during sports activities. The effects of footwear during other important daily work activities, such as the activities of soldiers, have been much less researched (Finestone et al., 1992; Milgrom et al., 1992). However, it is apparent that footwear should also have a large influence on these populations.

An athlete may spend one to two hours practicing or competing while wearing the same footwear. Army personnel, however, are often required to perform their tasks while wearing the same footwear for several hours. Thus, the choice of an appropriate boot is essential. Unfortunately, the guidelines for determining an appropriate boot for an individual are not well established.

A recent study attempted to determine the anthropometric and sensory factors which may predict the short term reaction of the foot to a set of selected shoe-insert constructions (Liu et al., 1998). The results can be summarized as follows:

- Small changes in insert properties produced significant and substantial changes in the comfort/acceptance rating in 106 university student subjects.
- Specific subject characteristics seemed to have an influence on the short-term comfort rating.
- Specific subject characteristics seemed to have an influence on the preferred choice of specific inserts.
- Foot sensitivity (tactile and vibration) and foot and leg alignment seemed to be a strong predictor for subject reactions.

Thus, shoe inserts appear to have the potential to improve comfort for individuals wearing combat boots. However, although there is some indication that specific variables such as leg alignment and sensitivity influence which insert an individual will find comfortable in the short term, these trends should be evaluated with a more long-term study. Furthermore, the influence of inserts on performance and lower extremity injuries in an actual military population executing military tasks needs to be determined.

The purposes of this study were to determine:

a) **lower extremity anthropometric and sensory factors which predict the comfort of selected boot-insert constructions in a military population and**
b) **the influence of boot inserts on lower extremity injuries and performance of a military population executing military tasks.**

LITERATURE REVIEW

Overuse injuries

Overuse injuries represent the largest percentage of sports-related injuries among athletes (O'Toole et al. 1989) and training-related injuries in military recruits that require medical treatment (Bennell & Brukner, 1997; Almeida et al., 1999). Recent estimates were that up to 60% of runners will experience an injury that will limit their activities (Brody, 1980; Jacobs & Berson, 1986; Lysholm & Wiklander, 1987; Marti et al., 1988). Most of these injuries were lower limb injuries including such maladies as patellofemoral disorders, shin splints, Achilles tendinitis, plantar fasciitis and various stress fractures. Lower limb injuries were reported to be the greatest source of medical problems during basic military training (Ross, 1993). Increased medical discharges were the consequence of increased lower limb injuries, as reported by the British Army (Jefferson, 1989). The pathogenesis of these overuse injuries is still not understood. However, the development of persistent pain in the lower limb following prolonged sustained intensive physical activity was reported to occur before the injuries (Volpin et al. 1989). The common causes of overuse injuries were suggested to include increased training volume (O'Toole et al., 1989), training errors and biomechanical factors (Rzonca & Baylis, 1988; Micheli 1986; Almeida et al., 1999; Jones & Knapik, 1999). In the lower extremity, risk factors include inappropriate progression of the rate, intensity and duration of training; anatomic malalignment; muscle-tendon imbalances of strength, endurance, or flexibility; footwear; surface; and pre-existent disease states.

Effect of shoe and shoe inserts

It has been suggested that impact forces during running and other activities are associated with the development of injuries and that the improvement of running shoes and surfaces reduce the frequency of impact related injuries (Miller, 1978; Nigg, 1978; McMahon & Greene, 1979; Cavanagh & Lafortune, 1980). In a prospective study, it was found that recruits who trained in basketball shoes had a lower incidence of overuse injuries of the feet than recruits who trained in infantry boots (Finestone et al., 1992; Milgrom et al., 1992). Although it was not measured directly, the effect of improved shock attenuation of vertical impact loads was speculated to account for the reduction of overuse injuries. A recent study showed that the incidence of stress fractures in infantry recruits could be reduced by 16.3% using soft biomechanical orthoses (Finestone et al., 1999). Recently, a concept of minimizing muscle work when using inserts has been proposed. According to this concept, the impact force signal acts as an input variable on the shoe. The shoe sole acts as a first filter, the insert as a second filter, and the plantar surface of the foot as a third filter for this input signal. The filtered information is transferred to the central nervous system and results in a subject specific dynamic response. The subject performs the movement for the task at hand. For a given movement task, the skeleton has a preferred path. If an intervention supports/counteracts the preferred movement path, muscle activity can be reduced/increased (Nigg et al., 1999). Based on this concept, an optimal insert would result in a decrease in muscle activity, improved footwear comfort, and increased performance.

It has been widely reported that shoe inserts are an effective interventional modality for the relief of discomfort to the feet associated with a variety of orthopedic disorders or conditions. A well constructed shoe insert can provide not only shock attenuation, but also appropriate arch support, better fit of the shoe and better control of rearfoot motion (Kilmartin & Wallace, 1994; Gross & Napoli, 1993). Shoe inserts have been shown to be effective in adjusting the biomechanical variables associated with running injuries and reducing the effect of high stresses produced by running activities. Shoe inserts have been successful in the treatment of lower limb osteoarthritis (Keating et al., 1993; Sasaki & Yasuda, 1987). In a study of conservative management of metatarsal and heel pain in the adult foot, D'Ambrosia (1987) suggested that foot orthotic devices may be the most useful treatment of metatarsal and heel pain. It was found necessary to prescribe orthotics in almost all cases of chronic problems to institute permanent relief.

Shoe comfort and overuse injuries

Individuals with overuse injuries of the lower limbs were observed to have persistent pain/discomfort before an injury occurs (Volpin et al., 1989; Ballas et al., 1997). The pain/discomfort may serve as a signal to indicate that an injury may be a long-term consequence. A semiflexible insert material was shown to reduce the discomfort in athletes and was suggested to reduce the overuse injury as well (Richie & Olson 1993). Repeated loading of the foot and excessive tension of the plantar fascia have been implicated by several authors as a cause of plantar fasciitis which results in symptomatic heel pain and inflammation (Campbell & Inman, 1974; Newel & Miller, 1977; Kwong et al., 1988). In order to avert such pathological results, it has been proposed that the objective of orthotic intervention is to resist depression of the foot's arch during weight bearing through skeletal support, thereby decreasing tension in the plantar aponeurosis (Campbell & Inman, 1974). When considering shoes, and specifically shoe inserts, increased comfort may simply indicate less risk of overuse injuries. Footwear comfort is one of the most important factors in selecting footwear. Every individual can chose a pair of shoes that is comfortable to wear despite the fact that the definition of and the scale to quantify shoe comfort is still not clear.

Foot structure and comfort

The influence of shoe inserts on motion of the lower limbs may depend on the structure of the foot. Several studies showed changes in joint motion and mechanics due to the use of different shoe inserts (Bates et al., 1979; Eng & Pierrynowski, 1994; Brown et al., 1995; Cornwall & McPoil, 1995). There is evidence showing that the dynamic motion of the foot is, to a certain degree, related to the structure of the foot (Fox, 1950; Rodgers, 1995; Duckworth, 1985; Hamil et al., 1989; Nigg et al., 1993; Cavanagh et al., 1997). Some studies suggested associations between foot structure and specific overuse injuries, such as patellar pain (Powers et al., 1995), anterior cruciate ligament (ACL) injury (Loudon et al., 1996), and tibial stress syndrome (Simkin et al., 1989; Sommer & Vallentyne, 1995). Foot structure and shape affect the comfort of the footwear (Hawes et al., 1994), often indicated as 'comfort fit' for the shoe. When studying the comfort of shoe inserts, the factors of structure and shape of the foot deserve consideration. Results of a recent study indicated that leg alignment may also be an important factor for footwear comfort (Liu et al., 1998).

Foot sensitivity and comfort

Shoe inserts may affect footwear comfort through the interaction with the human foot sensory system. The importance of plantar mechanoreceptors has been demonstrated in previous studies (Diener et al., 1984; Magnusson et al., 1990; Asai et al., 1992; Hamalainen et al., 1992). The effect of the receptors has been shown to vary with the interaction of standing surfaces (Watanabe & Okubo, 1981; Wu & Chiang, 1996; Ingersoll & Armstrong, 1992) and/or shoe inserts (Robbins et al., 1993; Chen et al., 1995). Robbins et al. (1993) found that the shapes and materials of shoe inserts influenced the balance of elderly men. Chen et al. (1995) showed that by changing sensory input to the feet, plantar pressure distribution changed significantly during gait. Foot sensitivity, especially vibration sensitivity, has been shown to be closely related to the preference for certain insert materials (Liu et al., 1998).

Shoe inserts and injuries

Shock absorption was suggested as the most important property of shoe inserts (Lewis et al., 1991). The use of a shock absorbing shoe insert was shown to reduce the incidence of soreness in the Achilles tendon, calf and back (Fauno et al., 1993). Viscoelastic shoe inserts reduced back, leg, and foot pain among adults who worked mostly in a standing position (Basford & Smith, 1988; Tooms et al. 1987), and in aerobic dancers (Clark et al., 1989). Most of the previous studies focused on only one single variable. The knowledge about the influence of shoe inserts on overuse injuries and shoe comfort is scattered. Liu et al. (1998) found that footwear comfort depends on material and shape of inserts in military boots but did not relate footwear comfort of insert conditions to a no insert condition.

Shoe inserts and performance

It has been suggested that an optimal shoe insert decreases the energy expenditure for a certain movement task (Nigg et al., 1999). Differences in shoe and shoe insert construction have been shown to cause differences in energy cost. Frederick et al. (1980) found that running air-sole shoes required less energy compared to running in non-air-soled shoes. These results were supported by Frederick et al. (1983). It has also been shown that hard shoe conditions require less metabolic energy than soft shoe conditions (Frederick et al., 1983). Using a mechanical model, Nigg & Anton (1995) showed that the estimated work required during a step cycle is generally higher for softer than for harder springs and for low damping compared to high damping. In addition, Stefanyshyn & Nigg (1998) found a trend towards lower energy consumption for running in a shoe with viscous material compared to elastic material in the heel region and for running in a shoe with elastic material compared to viscous material in the forefoot region. However, to date there is no systematic study of the effect of differences in material and shape of shoe inserts on oxygen consumption.

METHODS

General Procedure

A total of 206 military personnel from the Edmonton Garrison volunteered for this study. The subjects were split into two groups of 103 subjects, an insert group and a control group. Foot shape, leg characteristics, and foot sensitivity measurements were taken from all 206 subjects. Subjects in the insert group chose the most comfortable insert from a set of six boot inserts different in shape and material. The foot measurements and the comfort assessment were conducted at the PPCLI unit in Edmonton, Alberta. Subjects then wore the selected inserts for a period of four months. During these four months, subjects in both groups (insert group and control group) reported any pain or injuries they experienced. At the end of four months, eight subjects from the insert group performed oxygen consumption tests with and without their chosen inserts in their combat boots. The oxygen consumption tests were performed at the exercise physiology laboratory at the University of Alberta, Edmonton.

Subjects

A total of 206 military personnel (10 female, 196 male) volunteered for this study. The subjects' average age, height and weight are listed in Table 1.

Table 1. Mean age, height and weight of the participants of this study. Standard deviations are reported in brackets.

	All subjects n = 206	**Control Group n = 103**	**Insert Group n = 103**
Age [years]	28.5 (6.6)	28.1 (7.1)	28.9 (7.0)
Height [cm]	178.3 (6.5)	178.1 (7.2)	178.4 (8.5)
Weight [kg]	81.7 (10.4)	82.6 (10.6)	80.8 (11.1)

All subjects participated in regular military training at the time of the study. Prior to testing, the procedure was explained and informed written consent was obtained from each subject. Only subjects without any current musculo-skeletal or lower extremity disorders were included in this study. The subjects were randomly grouped into an insert group (n = 103) and a control group (n = 103). However, some restrictions for group membership were given by the regular military training schedule.

Procedure

Measurements of foot shape, leg characteristics, and foot sensitivity were obtained for each subject. The details of these measurements are provided in the *subject characteristics* section below.

Each subject in the insert group was asked to conduct marching trials while wearing each of six provided inserts on an outdoor course consisting of different surfaces including grass, gravel, concrete, and pavement. The vast majority of the subjects wore their Combat Boot Mark III

(Figure 1). The length of the boots used in this study ranged from 188 to 306 mm and the width from 84 to 118 mm.

Figure 1. Photograph of a pair of the Combat Boot Mark III used in this study.

The length and width of both feet of each subject were compared to the size of their boots. For ten subjects, the difference between foot and boot length was greater than 4 mm or the difference between foot and boot width was greater than 2 mm. These subjects were issued a correctly sized pair of boots.

Insert conditions

Six different shoe inserts (Figure 2), provided by Marketmall Shoe Repair (Calgary, Alberta), were used in this study. The inserts were commercially available inserts and then modified in material and shape. The inserts varied in shape, hardness, and elasticity. The specifications of these inserts are listed in Table 2.

Figure 2. The inserts used in this study with different shapes and materials.

Table 2. Specifications of the six different inserts used in this study.

	Shape		Hardness		Elasticity	
No.	Arch	Heel	Heel	Forefoot	Heel	Forefoot
1	high	spherical	hard	hard	elastic	elastic
2	high	spherical	soft	soft	elastic	elastic
3	high	spherical	soft	soft	viscous	viscous
4	high	spherical	soft	soft	viscous	elastic
5	low	spherical	soft	soft	viscous	elastic
6	high	flat	soft	soft	elastic	elastic

The inserts were built to fit the Combat Boot Mark III and were available for boot sizes 7 to 13.5. The six inserts resulted in six insert pairings that differed in only one shape or material characteristic:

Insert pairing	Shape or material differences
# 2 – # 1	hard vs. soft
# 3 – # 2	viscous vs. elastic
# 4 – # 3	elastic vs. viscous forefoot
# 4 – # 2	viscous vs. elastic heel
# 5 – # 4	low vs. high arch
# 6 – # 5	flat vs. spherical heel

Subject characteristics

The subject characteristics quantified for all 206 subjects in this study include foot shape, arch height, foot and leg alignment, and tactile and vibration sensitivity of the plantar surface of the foot. A previous study showed that there is no significant difference in foot sensitivity between the left and the right foot (Bell-Krotoski et al. 1995). All measurements were taken from the left foot of each subject in agreement with Liu et al. (1998).

Foot and leg characteristics

Foot shape, foot arch and leg characteristics were measured by digitization of the foot and leg while the subject was standing on the testing table with the measured foot loaded with body weight. No additional load was applied to the subject during the digitization procedure. An electro-magnetic digitizing device (3Space Fasttrak by Polhemus) was used in this study (Figure 3). The device had an accuracy of 0.7 mm for spatial position in a 76 x 76 x 76 cm cubic space. A transmitter fixed on the corner of a testing table emitted the magnetic field. A stylus with a precision tip was used to identify the point to be digitized. The stylus contained a receiver detecting the magnetic field emitted by the transmitter. The testing table was a wooden board raised 44 cm above the floor to minimize the influence from any metal materials under the floor. There were no metallic materials on the table while digitizing was conducted.

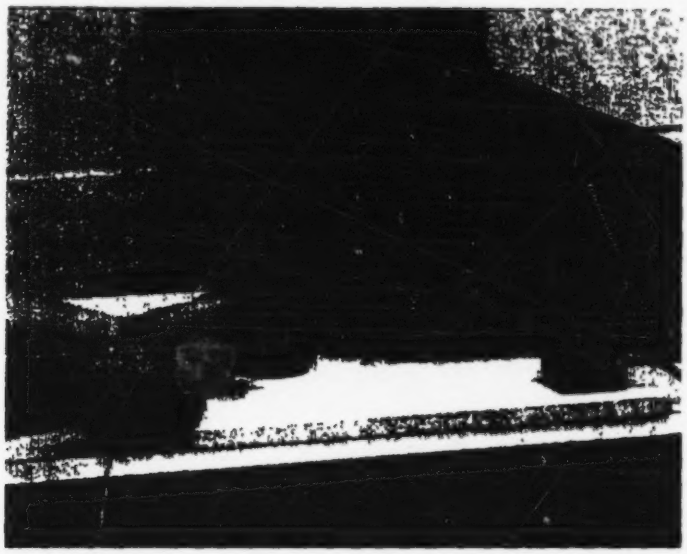


Figure 3. Photograph of the set up for the digitization measurements on the left foot of a subject.

An anatomical reference frame was defined before any measurements on the foot were taken (Figure 4). The x-axis was a line formed by the projection onto the testing table of a plane which touched the edge of the medial aspect of the foot. The two contact points were close to the first metatarsal joint and the most medial point of the heel. The y-axis was a line formed by the projection onto the table of a plane perpendicular to the x-axis, which touched the edge of the posterior aspect of the heel. The z-axis was perpendicular to both the x- and the y-axis pointing upwards. A jig consisting of two perpendicular plastic bars with two sliding blocks on one bar was built to help in the determination of the reference frame. Three small recess holes on the surface of the jig, as marked by O, X, and Y (Figure 4), were digitized to establish the reference frame.

A total of 26 points on the surface of the foot and leg were selected for digitization (Table 3), as indicated in Figures 4 to 6. From the digitized coordinates of the 26 points, a total of 23 variables were calculated (using the DigFoot 2.0 program, Lars Mündermann, University of Calgary, Alberta) to represent the characteristics of the shape, dimension, and structure of the foot and leg (Table 4). The program first established a coordinate system from the coordinates of the digitized points O, X, and Y and then shifted the reference frame along the three axis compensating the offsets of this coordinate system. The coordinates of all digitized points were then converted from a global reference frame attached to the transmitter of the digitizer device to above reference frame. Finally, the program computed all parameters from the coordinates of the digitized points.

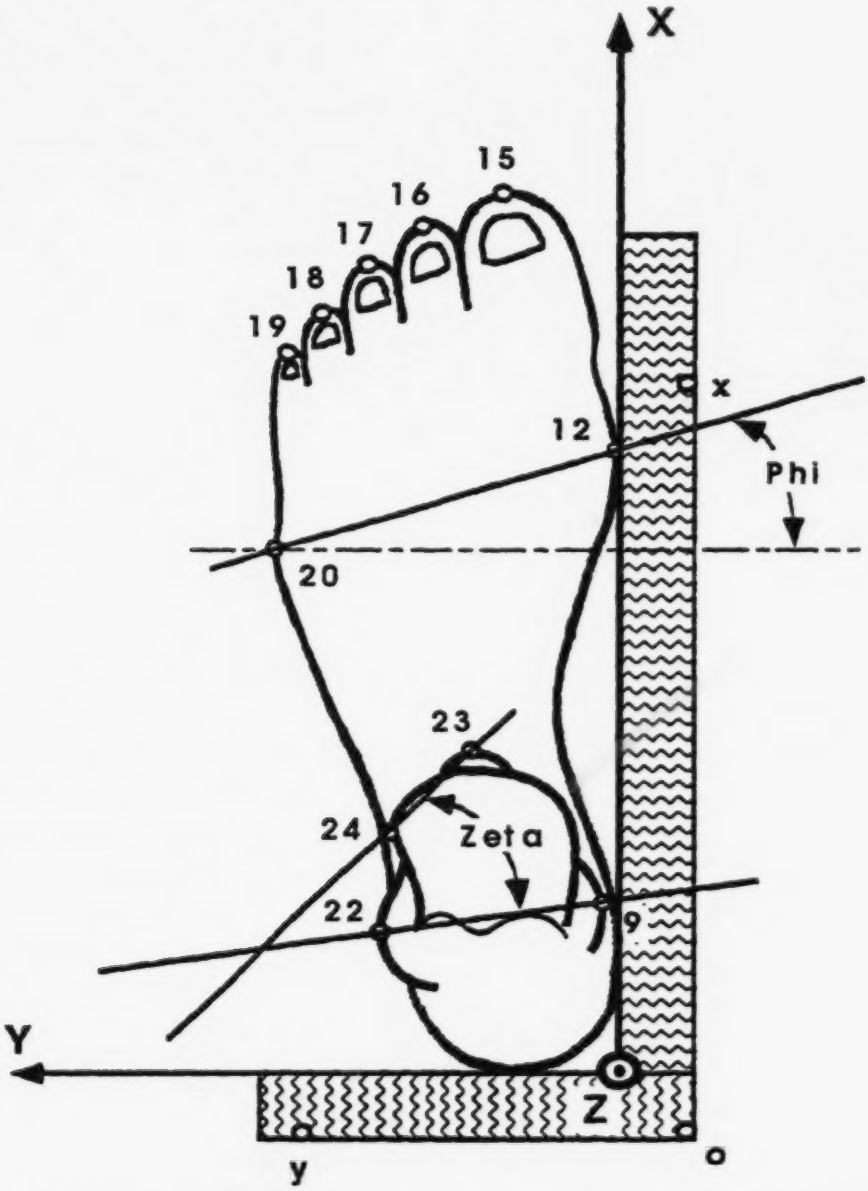


Figure 4. Superior view of the left foot with an anatomically defined reference frame. All marked points were the points for digitization.

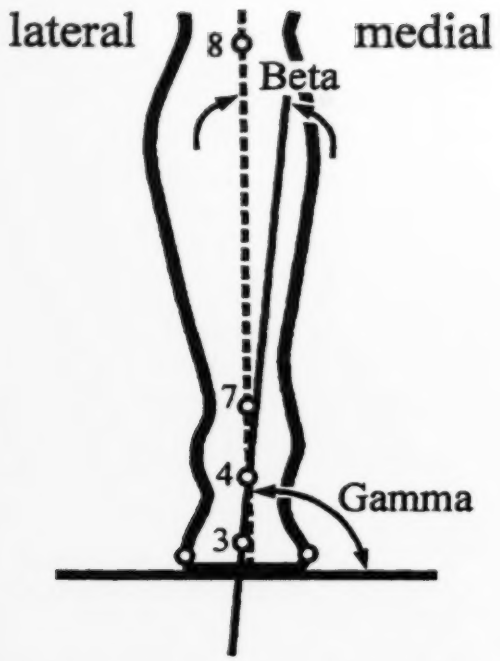


Figure 5. Posterior view of the left foot and leg with digitized points marked.

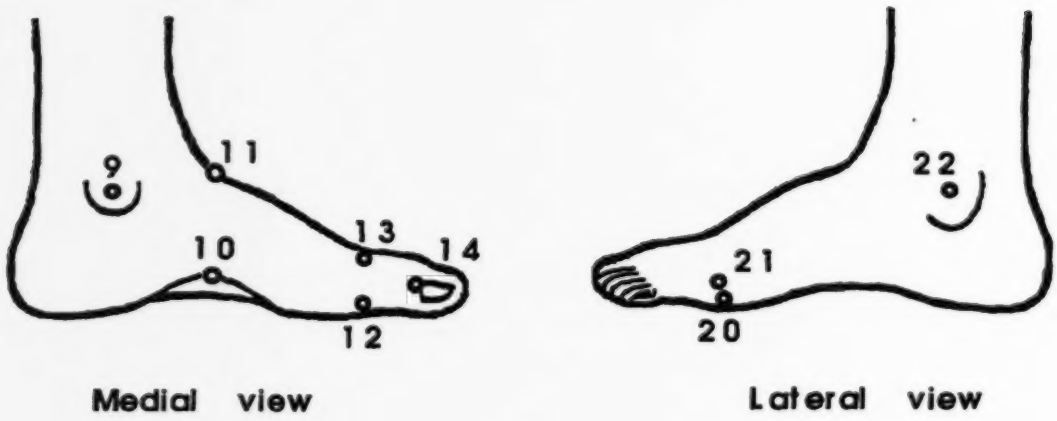


Figure 6. Left foot with digitized points marked.

Table 3. Definition and description of digitized points.

No.	Digitized Point	Definition
1	lateral edge of heel	a point on the lateral heel, 2-3 mm above standing surface, about 3 cm anterior to the pternion
2	medial edge of heel	a point on the medial heel, 2-3 mm above standing surface, about 3 cm anterior to the pternion
3	distal posterior heel	a point on the bisection of the posterior calcaneus, 2-3 mm above standing surface
4	proximal posterior heel	a point on the bisection of the posterior calcaneus, about 4 cm above standing surface
5	lateral pternion	a point at lateral side representing maximum width of the calcaneus at pternion level
6	medial pternion	a point at medial side representing maximum width of the calcaneus at pternion level
7	distal bisection of leg	a point on the bisection line of posterior lower leg and at the distal part of the lower leg
8	proximal bisection of leg	a point on the bisection line of posterior lower leg and at the level of one third of the lower leg
9	medial malleolus	center point of medial malleolus
10	arch height point	intersection of a vertical frontal plane passing through talus head on the margin of the medial plantar curvature
11	dorsum height point	a point on the superior surface of the head of the talus
12	1st MH medial point	the most medially prominent point on the first metatarsal head
13	1st MH height point	the superior point of the first metatarsal head
14	hallux height point	a point on superior surface of the hallux
15	1st digit length point	the most prominent point on the first digit
16	2nd digit length point	the most prominent point on the second digit
17	3rd digit length point	the most prominent point on the third digit
18	4th digit length point	the most prominent point on the fourth digit
19	5th digit length point	the most prominent point on the fifth digit
20	5th MH lateral point	the most laterally prominent point on the 5th metatarsal head
21	5th MH height point	the superior point of the 5th metatarsal head
22	lateral malleolus	center point of the lateral malleolus
23	tibial tuberocity	center point of tibial tuberocity
24	fibular head	center point of fibular head
25	patella center	center point of patella
26	ASIS point	center point of the anterior superior iliac spine

Table 4. Foot variables calculated from coordinates of digitized points.

Variables	Name	Calculated as
Height		
H_{dorsum}	dorsum height	Z(11)
H_{arch}	maximum arch height	Z(10)
Length		
L_{1T}	length of heel to the first digit	X(15)
L_{2T}	length of heel to the second digit	X(16)
L_{3T}	length of heel to the third digit	X(17)
L_{4T}	length of heel to the fourth digit	X(18)
L_{5T}	length of heel to the fifth digit	X(19)
L_{1MH}	length of heel to the 1st MH medial point	X(12)
L_{5MH}	length of heel to the 5th MH lateral point	X(20)
L_{dorsum}	length of heel to the dorsum	X(11)
Width		
W_{1T}	the distance from tip of the first digit to y axis	Y(15)
W_{2T}	the distance from tip of the second digit to y axis	Y(16)
W_{3T}	the distance from tip of the third digit to y axis	Y(17)
W_{4T}	the distance from tip of the fourth digit to y axis	Y(18)
W_{5T}	the distance from tip of the fifth digit to y axis	Y(19)
W_{heel}	maximum heel breadth	Y(1)-Y(2)
$W_{forefoot}$	foot breadth measured from first metetarsal to 5th metatarsal	Y(20)-Y(12)
Angle		
φ	Forefoot flexion angle	*
ρ	Tibia torsion angle	**
γ	Heel angle	***
β	Achilles tendon angle	****
Q-angle	Q-angle of the leg	*****

* This angle was measured in xz plane between a line connecting point 3 and 4 and the horizontal line

** This angle was measured in xy plane between a line connecting point 12 and 20 and x axis

*** This angle was measured in xz plane between a line connecting point 3 and 4 and a line connecting point 7 and 8

**** This angle was measured in xy plane between a line connecting point 9 and 22 and a line connecting point 23 and 24

***** This was the angle in xz plane between a line connecting point 23 and 25 and a line connecting point 25 and 26

The variables included heights, lengths, widths, and angles of the foot and leg. All height variables (named H) were calculated as vertical distances from the testing table to the digitized points; all length variables (named L) were calculated along the x-axis; all width variables (named W) were calculated along the y-axis. Five angles were calculated. The heel resting position angle γ was the angle calculated in the yz-plane between the bisection line of the heel and the z-axis. In the present study, the heel angle was measured with respect to a horizontal line in comparison to the vertical line as used by Liu et al. (1998). In addition, angles greater as well as smaller than 90° were measured corresponding to eversion and inversion. The forefoot flexion angle φ was the angle enclosed by the y-axis and a line connecting the first and fifth metatarsal joints. The angle of the heel to the tibia β was the angle between the bisection lines of the heel and the lower leg measured in the yz-plane. The tibia torsion angle ρ was the projected angle between a line connecting the two malleoli and a line connecting the tibial tubercle and the center point of the fibular head on the xy-plane. The Q-angle of the knee joint was the angle between a line connecting the tibial tubercle and the center of the patella and a line connecting the center of the patella and the point of the anterior superior iliac spine (ASIS) projected onto the yz-plane. Except for the Q-angle, which was measured during bipedal standing, all variables were measured during single leg support as the other leg rested on a platform to maintain balance (Robinson and Frederick, 1989). The five angles represented the structural characteristics of the lower extremities, which have been found to be correlated to sports injuries (Cavanagh et al., 1997; Hamill et al., 1989; Messier et al., 1991).

Foot sensitivity

The sensitivity of the plantar surface of the foot was evaluated by a touch pressure threshold test and by a vibration sensitivity threshold test. Touch pressure threshold was determined using Semmes-Weinstein monofilaments (North Coast Medical, Inc.) (Figures 7 and 8). Each filament had a specified diameter and was marked with a specific number that is equal to log (10* buckling force (mg)) (Levin et al, 1978). A set of filaments, which contained the 1.65, 2.36, 2.83, 3.61, 4.08, 4.31, 4.56, 5.07 and 6.65 monofilaments, was used in this study. During the test, the subject lay down in a quiet room, with a curtain preventing any view of his/her foot and the examiner. The examiner controlled a light seen by the subject and the touch stimulus was applied only when the light was on. The light was an indication for the subject to concentrate and respond whether or not a pressure sensation was felt in the area of the foot to be tested. A modified 4-2-1 stepping algorithm (Dyck et al., 1993) was used to determine the pressure threshold at three locations on the left foot of each subject (heel, medial arch, and hallux). The 1st and 5th metatarsal head locations were not tested in this study because their tactile sensitivity threshold correlated to the sensitivity threshold at the hallux (Liu et al., 1998).

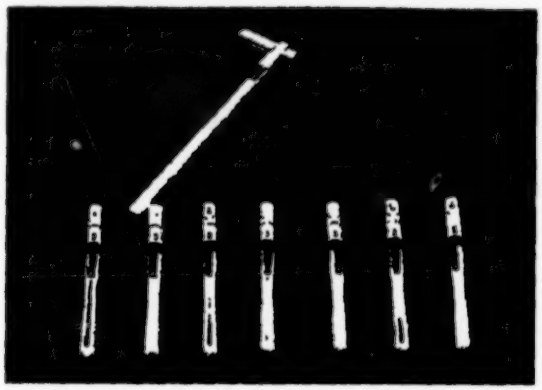


Figure 7. Photograph of the set of monofilaments (foot kit) used in this study.

Figure 8. Photograph of the setup of touch sensitivity measurement.

Vibration sensitivity thresholds were determined using a vibration exciter (Bruel and Kjaer, type 4809) powered by an oscillator (Bruel and Kjaer, type 1022) with variable amplitude and frequency of vibration (Figure 9). A metal probe 8 mm in diameter was screwed into the vibration exciter and fed through a wooden foot rest. The steel probe had a flat surface with rounded edges. The diameter of the hole in the footrest was 13 mm, and the probe protruded 1.5 mm through the footrest. An accelerometer (Bruel and Kjaer, type 4367) was mounted beside the metal probe on the exciter and was attached to a RMS multimeter (Fluke 8060A) through a signal conditioner. The use of an accelerometer allowed for accurate measurement of the probe's movement and compensated for the various damping effects of different locations on the foot. Each subject's left foot was tested at three locations: the heel, first metatarsal, and hallux. The test was performed using a method of increasing and decreasing amplitude at 30 Hz and at 125 Hz (Peripheral Neuropathy Association, 1993). The amplitude was increased until the subject reported feeling the vibration stimulus – the vibration perception threshold (VPT). The amplitude was then immediately decreased until the subject reported that he/she could no longer feel the stimulus – the vibration disappearance threshold (VDT). This was repeated five times in

succession so that a total of ten measurements were obtained. The vibration sensitivity threshold was calculated by removing the highest and the lowest VPT's and VDT's, and averaging the remaining six values. The accelerometer was calibrated to the acceleration such that 1 g corresponded to 2.2 V from the multimeter. Displacement values were obtained based on known calibration of the accelerometer.

The following sensitivity variables were analyzed in this investigation:

Tactile (touch pressure) sensitivity

T_{heel}	tactile sensitivity threshold at the heel: threshold filament number
T_{march}	tactile sensitivity threshold at the medial arch: threshold filament number
T_{hallux}	tactile sensitivity threshold at the hallux: threshold filament number

Vibration sensitivity

$V_{heel, 30}$	vibration sensitivity threshold at 30 Hz at the heel, in μm
$V_{mh1, 30}$	vibration sensitivity threshold at 30 Hz at the first metatarsal head, in μm
$V_{hallux, 30}$	vibration sensitivity threshold at 30 Hz at the hallux, in μm
$V_{heel, 125}$	vibration sensitivity threshold at 125 Hz at the heel, in μm
$V_{mh1, 125}$	vibration sensitivity threshold at 125 Hz at the first metatarsal head, in μm
$V_{hallux, 125}$	vibration sensitivity threshold at 125 Hz at the hallux, in μm

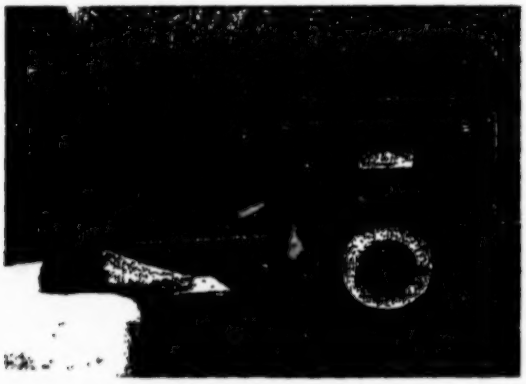


Figure 9. Photograph of the setup of vibration sensitivity measurement.

The outcome criteria

Subjective comfort

Subjects in the insert group marched with each insert in their boots on an outdoor course consisting of different surfaces including grass, gravel, concrete, and pavement (approximately 500 m). For each insert condition, they evaluated the subjective short-term comfort using a comfort questionnaire (Appendix A). The first trial for all subjects was the issued insert

condition. The subjects completed the course and then rated the comfort of this condition on a visual scale. The left end of the scale was labeled 'not comfortable' and corresponded to a comfort rating 0, the right end of the scale was labeled 'very comfortable' (comfort rating 10). This procedure was then repeated for each of the six insert conditions. The six insert conditions were evaluated in a random order without the subject's awareness. Each subject marched at his/her preferred speed during each trial.

In order to test the repeatability of the subjective comfort rating, each subject actually evaluated seven insert conditions (six inserts plus one that was repeated). Thus, each of the six inserts were evaluated twice by at least sixteen subjects. The order of the repeated insert within the six tested inserts was randomly selected without the subject's awareness.

A paired t-test was used to assess the repeatability of the subjective comfort ratings. An analysis of variance (ANOVA) test was used to determine the significance level of the variance of subjective comfort ratings for six inserts. Paired t-tests were conducted to identify the significant differences between different shoe inserts ($\alpha = .05$).

The difference in overall comfort rating was analyzed for each insert combination. A difference at the significance level $\alpha = .05$ was a strong indication for a general difference in comfort between two inserts. The goal of this study was also to detect foot characteristics (foot shape, foot and leg alignment, and foot sensitivity) that are important factors for footwear comfort. The relationship between insert comfort and foot characteristics is multi-factorial. Thus, two different forms of comparisons were used to find trends in the relationship between foot characteristics and insert comfort. Six insert pairings were analyzed, each pairing of inserts differed in either one shape or one material characteristic. The possible insert combinations are listed in Table 5.

Table 5. Insert combinations and their differences in shape or material.

Insert combination	Shape or material difference
#2 vs. #1	soft vs. hard heel and forefoot region
#3 vs. #2	Viscous vs. elastic heel and forefoot region
#4 vs. #3	Elastic vs. viscous forefoot region
#4 vs. #2	Viscous vs. elastic heel region
#5 vs. #4	low arch vs. high arch
#6 vs. #2	flat vs. spherical heel shape

The first comparison used foot characteristics (foot shape, foot and leg alignment, and foot sensitivity) as the criterion to form groups. For each measured foot characteristic, the 15 subjects with the highest values and the 15 subjects with the lowest values were determined. For example, the 15 subjects with the highest arch heights formed the high arch height group and the 15 subjects with the lowest arch height formed the low arch height group. The group size of 15 subjects was chosen because most of the foot characteristics had approximately 15 subjects with values higher or lower than one standard deviation away from the mean. The overall insert comfort rating and the specific insert comfort ratings were determined for high and low groups of each foot characteristic. A difference at the significance level $\alpha = .10$ between insert comfort

rating or specific insert comfort rating between the two groups was reported as a trend that this particular foot characteristic was an important factor.

The second comparison used the overall insert comfort rating and the specific insert comfort ratings between two conditions as the criterion. Those subjects (n = 15) that most preferred the first insert over the second one (group 1) were compared with those subjects (n = 15) that most preferred the second insert over the first one (group 2). Specific foot characteristics were compared between the two groups. A difference at the significant level α = .10 in foot characteristics between groups was reported as a trend that this specific foot characteristic was an important factor.

An agreement of the results of both comparisons indicated strong support for the importance of the specific foot characteristic. Summary tables are presented for each insert combination. The last column in the table states the agreement of the results of this investigation with Liu et al. "yes"/"no" stands for an agreement/disagreement of the results of both studies. A "-" means that this specific subject characteristic was not reported as an important factor for footwear comfort in the previous study.

Injury assessment

All 206 subjects were asked to record physical activities and any injuries or pain in a personal logbook, which was provided by the investigators (Appendix C). Four months after the initial assessment, subjects were given a questionnaire to determine the occurrence, frequency and severity of injuries and pain experienced (Appendix B). Subjects were asked if they had any pain or injury during the last four months and if they had seen a physician. If a subject reported an injury he/she was asked for the kind of the injury, its location, duration, and frequency. Based on this information, χ^2 tests were conducted to detect significant differences of the number and the severity of injuries and their location between the insert and the control group (α = .05).

Performance testing

Eight subjects in the insert group were randomly selected for performance tests on three consecutive days. On the first day, the anaerobic threshold was determined using a marching protocol. First, the subject warmed up marching for approximately 10 minutes at 1.5 m/sec on a treadmill (Marquette Electronics Inc., Model 1800 and Quintan Instruments, Model 18-60). The headgear and the mouthpiece were put on and connected to the metabolic cart (MedGraphics CPXD, MedGraphics Corporation). The subjects marched at 1.5 m/sec at a 1° incline carrying their backpack (approximately 20 kg). The incline was increased in 2° increments every two minutes until exhaustion or the leveling off of $\dot{V}O_2$. During the test, the oxygen and carbon dioxide content of the expired air were measured. Before and after each test a calibration with gases of known concentrations was performed. From this data, the treadmill incline equivalent to the anaerobic threshold was determined and the maximum oxygen consumption value recorded.

On the second and third day, $\dot{V}O_2$ submaximum tests were conducted. The subjects performed four consecutive tests of 6 minutes each at 1.5 m/sec and 3° incline carrying the same backpacks as on the first day. The incline was selected such that all subjects marched below their anaerobic

threshold. For each subject, the insert condition was the combat boots with his most comfortable inserts and the issued insert condition was the combat boots with the standard issued insert. On one day, the order of trials for one subject was insert – issued insert – issued insert – insert, on the other day the order was reversed. For each trial, the oxygen uptake values for the last four minutes were averaged. If the fluctuation between the values for one trial was larger than one percent, the trial was excluded from the analysis. For each subject, the difference of the mean of the $\dot{V}O_2$ values of the four insert trials and the mean of the four issued insert trials was calculated.

RESULTS AND DISCUSSION

Measured subject characteristics

Foot and leg characteristics

The measured foot and leg characteristics are summarized in Table 6. The variation of all parameters is rather high with standard deviations as high as 13.73 mm for the length of the second toe. This can be explained by the fact that both female and male subjects were included in this study and that the foot lengths ranged from 221.2 to 298.8 mm. Except the values for the heel angle γ, the range of all parameters are in agreement with Liu et al. (1998). The Achilles tendon angles were generally larger in the present study than in Liu et al., which could be related to the different testers that performed the actual digitization.

Foot sensitivity

Tactile sensitivity

In general, subjects had a lower threshold at the medial foot arch compared to the heel and the hallux. The sensitivity threshold at the heel was higher than the threshold at the hallux. The subjects in this study were most sensitive at the medial arch, sensitive at the hallux, and least sensitive at the heel. The range of tactile sensitivity thresholds at the hallux (1.65 to 6.65) was larger than the thresholds at the medial arch and at the heel (1.65 to 4.31 and 2.83 to 6.65). The distributions of the monofilament thresholds at the three tested locations show different patterns (Figure 10). The distribution of the thresholds at the medial arch is shifted towards lower thresholds compared to the distribution for the heel. The distribution of the thresholds at the hallux is centered between the distributions at the heel and at the medial arch. An analysis of tactile sensitivity thresholds using Wilcoxon matched-pairs signed-ranks test showed significant differences between the tested locations ($p < .001$). These results are in agreement with Liu et al. (1998).

Table 6. Average (standard deviation), maximum and minimum foot dimensions including heights (H), lengths (L), widths (W), and angles of the 206 military personnel measured in this study.

Variables	Average [mm]	Maximum [mm]	Minimum [mm]
Height			
H_{dorsum}	73.7 (6.3)	89.9	49.5
H_{arch}	16.4 (4.0)	31.0	6.4
Length			
L_{1T}	266.5 (13.3)	298.8	221.2
L_{2T}	260.3 (13.7)	297.2	215.4
L_{3T}	248.5 (13.3)	283.8	205.4
L_{4T}	232.4 (12.3)	266.1	191.4
L_{5T}	211.1 (11.3)	245.2	171.5
L_{1MH}	197.1 (10.7)	227.2	165.9
L_{5MH}	163.5 (9.5)	192.0	134.6
L_{dorsum}	110.0 (7.8)	133.9	89.7
Width			
W_{1T}	30.2 (8.4)	55.9	8.6
W_{2T}	56.8 (7.8)	90.6	37.6
W_{3T}	72.5 (7.4)	102.6	54.0
W_{4T}	85.0 (7.1)	108.9	68.1
W_{5T}	95.6 (6.9)	120.6	78.6
W_{heel}	65.5 (4.0)	76.4	55.1
$W_{forefoot}$	101.2 (6.4)	117.0	82.9
Variables	**Average [°]**	**Maximum [°]**	**Minimum [°]**
Angle			
forefoot flexion angle φ	18.2 (2.9)	26.5	11.2
tibia torsion angle ρ	29.9 (7.7)	49.0	9.9
heel angle γ	92.0 (3.2)	101.8	83.8
Achilles tendon angle β	18.7 (4.4)	34.9	7.7
Q-angle	20.6 (4.8)	35.4	4.4

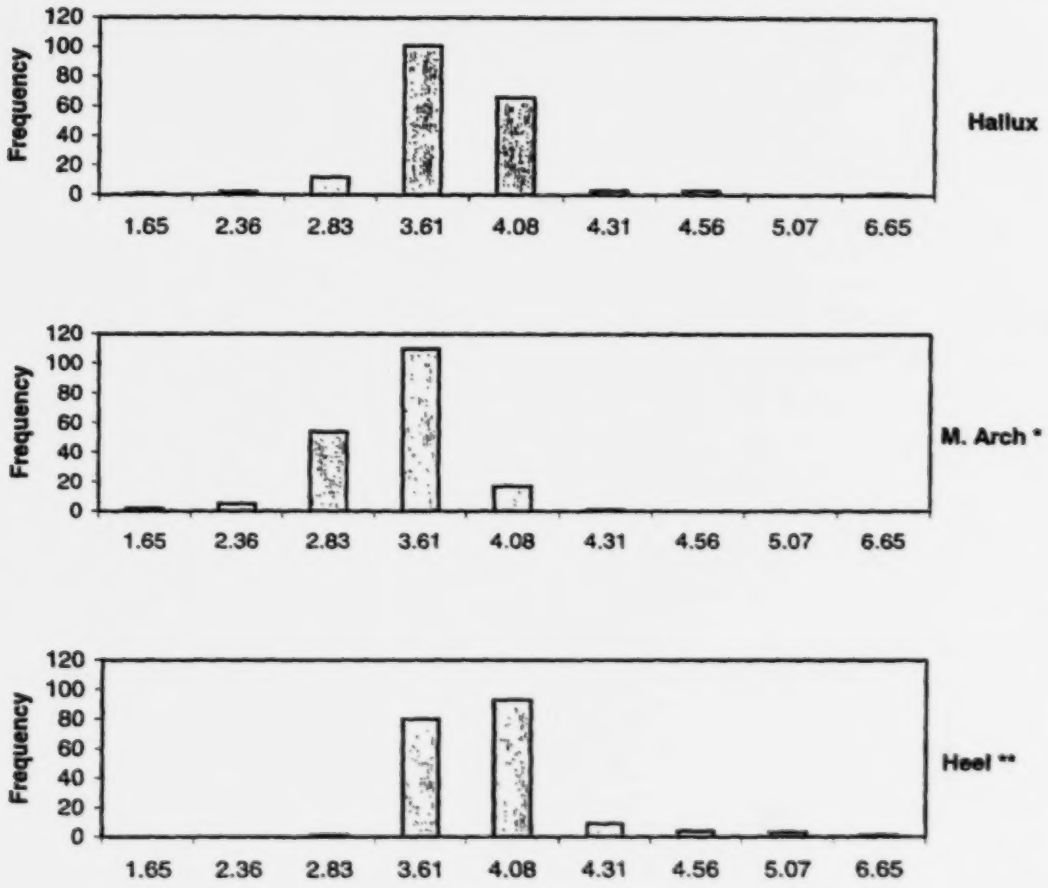


Figure 10. Distribution of monofilament thresholds at three different locations of the feet of 206 subjects. * significant difference compared to hallux; ** significant difference compared to medial arch and hallux ($p < .001$).

Vibration sensitivity

An analysis of variance (ANOVA) of different locations at the foot showed a significant difference in vibration sensitivity threshold between locations ($p < .001$). The vibration sensitivity threshold at 30 Hz was significantly lower at the first metatarsal head and the heel compared to the hallux (Figure 11). The threshold at 125 Hz was significantly lower at the first metatarsal head compared to the hallux and the heel (Figure 12).

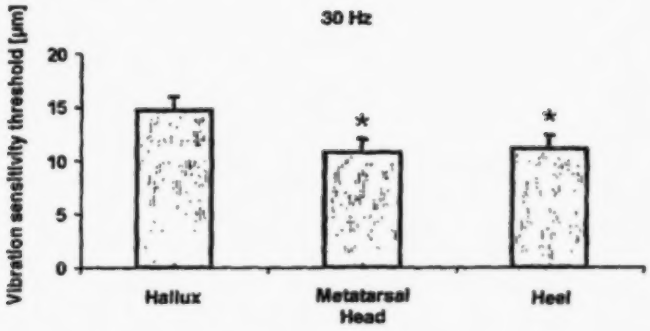


Figure 11. Mean and standard error of the vibration sensitivity threshold [µm] at 30 Hz for three locations for 206 subjects. * significant lower vibration sensitivity compared to the hallux location.

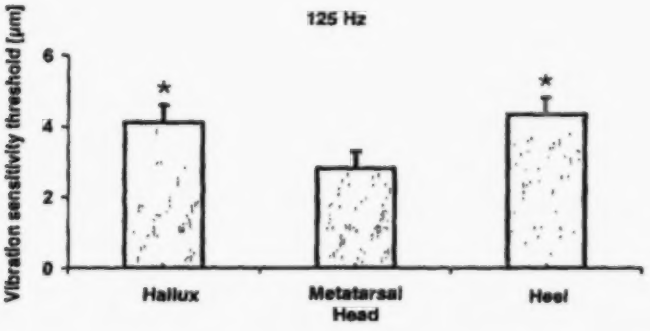


Figure 12. Mean and standard error of the vibration sensitivity threshold [µm] at 125 Hz for three locations for 206 subjects. * significant higher vibration sensitivity compared to the metatarsal head location.

The vibration sensitivity thresholds at 30 Hz at all locations were higher compared to the thresholds at 125 Hz (Figures 13 and 14). The distributions of vibration sensitivity thresholds at 30 Hz showed a similar pattern for all tested locations. Most subjects had a threshold between 4 and 14 µm. None of the subjects had a threshold lower than 2 µm at the heel (Figure 13).

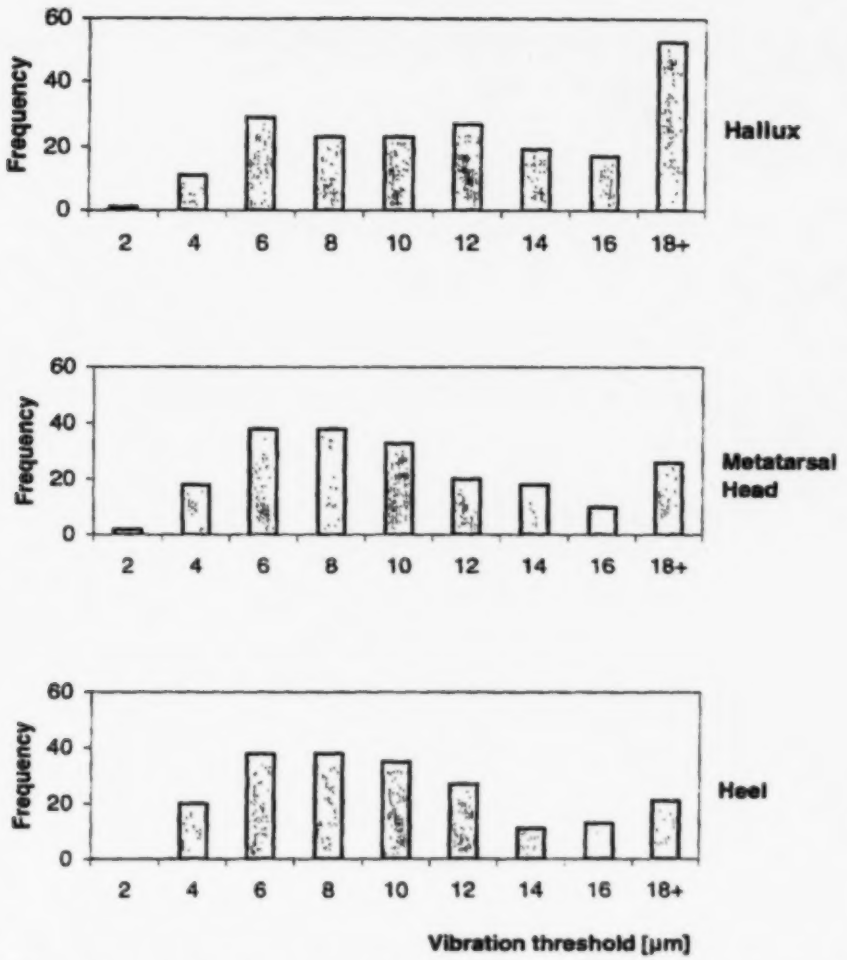


Figure 13. Distribution of vibration sensitivity thresholds [μm] at 30 Hz for three different locations of the left feet of 206 subjects. The vibration sensitivity threshold was divided into nine intervals with 2 representing the threshold value within 0-2 μm, and so on. 18+ represents all thresholds greater than 18 μm.

The distributions of the vibration sensitivity threshold at 125 Hz showed similar patterns for the three tested locations (Figure 14). The vibration sensitivity threshold for most subjects was smaller than 2 μm which is in agreement with Liu et al. (1998).

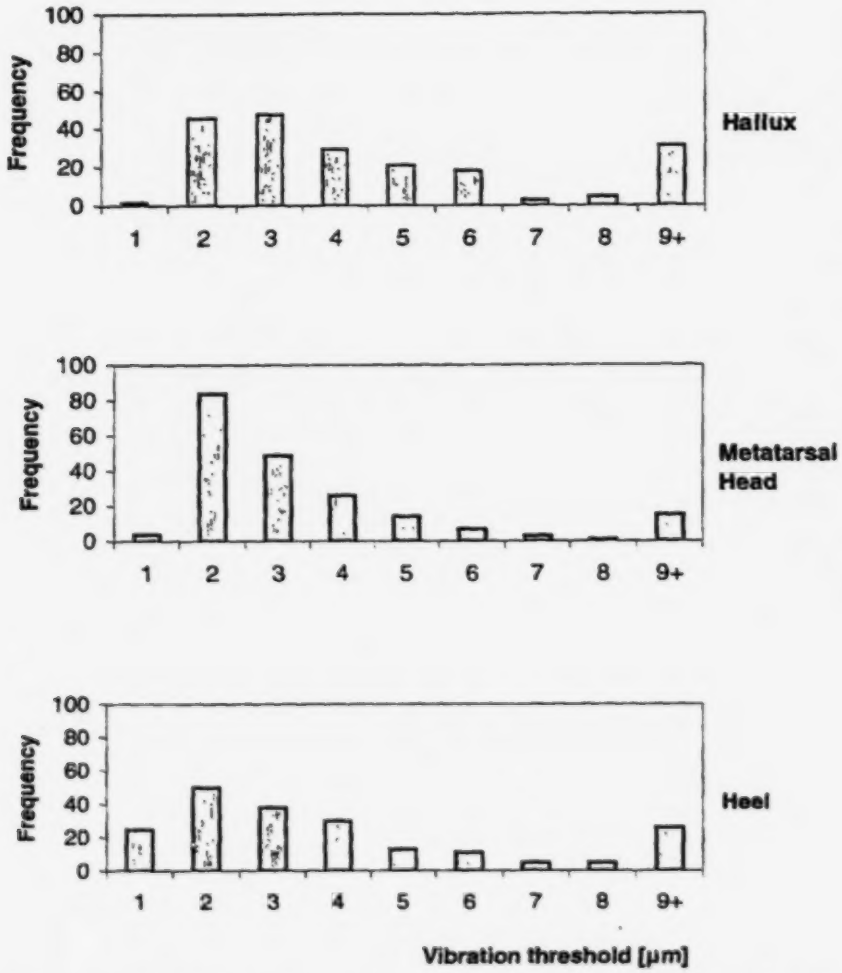


Figure 14. Distribution of vibration sensitivity thresholds [µm] at 125 Hz for three different locations of the left feet of 206 subjects. The vibration sensitivity threshold was divided into nine intervals with 1 representing the threshold value within 0-1 µm, and so on. 9+ represents all thresholds greater than 9 µm.

However, more subjects had a threshold higher than 9 µm compared to Liu et al. In average, subjects with a vibration sensitivity threshold greater than 9 µm were older than subjects with a vibration sensitivity threshold below 9 µm. The difference in age between these two groups was 4.9 years at the hallux, 7.2 years at the metatarsal head, and 5.8 years at the heel. These differences are approximately the difference in average age between the study of Liu et al. (23 years) and the current study (28 years) (Figure 15). This trend could not be observed for the vibration sensitivity thresholds at 30 Hz (Figure 16).

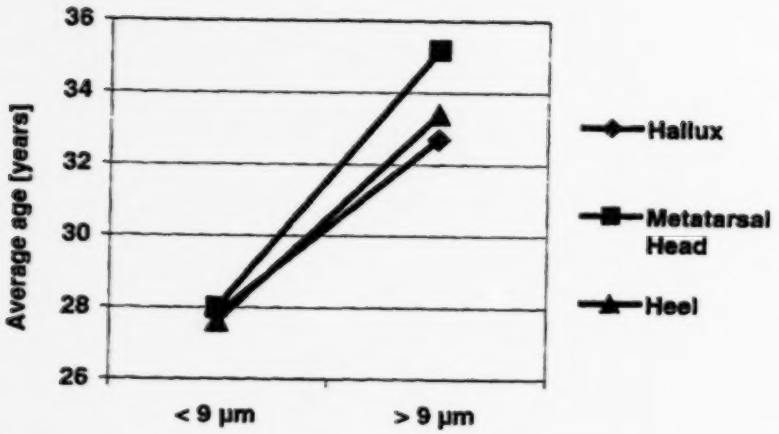


Figure 15. Difference in average age for subjects with a vibration sensitivity threshold at 125 Hz smaller or greater than 9 µm ($n_{hallux, < 9\mu m} = 176$; $n_{hallux, > 9\mu m} = 30$; $n_{metatarsal\ head, < 9\mu m} = 192$; $n_{metatarsal\ head, > 9\mu m} = 14$; $n_{heel, < 9\mu m} = 176$; $n_{heel, > 9\mu m} = 30$)

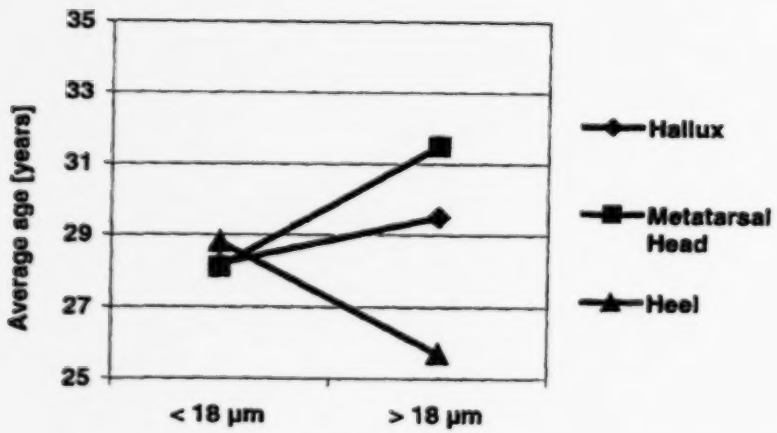


Figure 16. Difference in average age for subjects with a vibration sensitivity threshold at 30 Hz smaller or greater than 18 µm ($n_{hallux, < 18\mu m} = 157$; $n_{hallux, > 18\mu m} = 49$; $n_{metatarsal\ head, < 18\mu m} = 184$; $n_{metatarsal\ head, > 18\mu m} = 22$; $n_{heel, < 18\mu m} = 185$; $n_{heel, > 18\mu m} = 21$)

Subjective comfort

All results for comfort ratings are based on comfort questionnaires of 103 subjects.

Repeatability

The difference in the mean value of comfort ratings between two repeated tests on the same insert was 0.53 comfort points. The correlation coefficient R for repeated tests was 0.35 ($p < .001$).

Maximum and range of comfort ratings

The highest comfort rating and the range between the lowest and the highest comfort rating were determined for each subject in the insert group. The maximum comfort ratings of all 103 subjects were between 3.2 and 9.8 comfort points. The range of comfort ratings given to the seven insert conditions was between 1.0 and 9.4 comfort points.

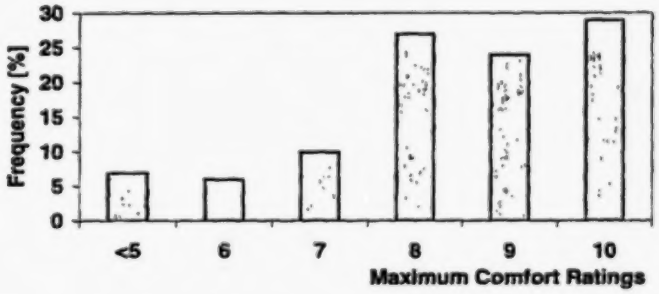


Figure 17. Distribution of the maximum comfort ratings given by the subjects in the insert group (0 – not comfortable, 10 – very comfortable). 100% corresponds to n = 103 subjects.

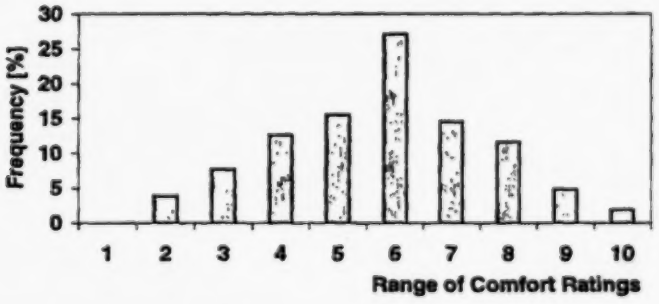


Figure 18. Distribution of the range of comfort ratings given by the subjects in the insert group. 100% corresponds to n = 103 subjects.

The distributions of the maxima and the ranges of comfort ratings are shown in Figures 17 and 18. Ninety percent of the subjects gave a maximum rating larger than 5.6 comfort points and the range of the given comfort ratings of eighty percent of the subjects was at least 3.0 comfort points.

Distribution of comfort ratings

The distribution of comfort ratings for the issued insert condition showed a different pattern than the distributions of comfort ratings for all insert conditions (Figures 19 and 20). The majority of subjects perceived the issued insert condition as extremely uncomfortable.

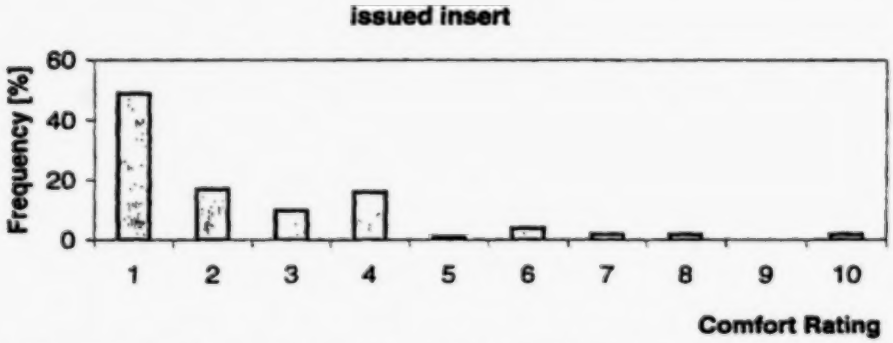


Figure 19. Distributions of comfort ratings for the issued insert condition (0 – not comfortable, 10 – very comfortable).

The comfort ratings were generally close to evenly distributed for all boot inserts evaluated in this study (Figure 20). However, small differences in distributions of comfort ratings between inserts were observed. The distribution for insert #1 was shifted to smaller comfort ratings compared to the remaining inserts. The distribution of comfort ratings for insert #5 showed two peaks. This indicated that one group of subjects perceived the low arch insert more comfortable than a second group.

Differences in comfort ratings

The shape and material characteristics and the average comfort ratings of the six boot inserts used in this study are listed in Table 7. Insert #6 had the highest average comfort rating among all tested insert conditions as opposed to insert #2 in Liu et al. (1998). The lowest average comfort rating was given to insert #1 in agreement with Liu et al.

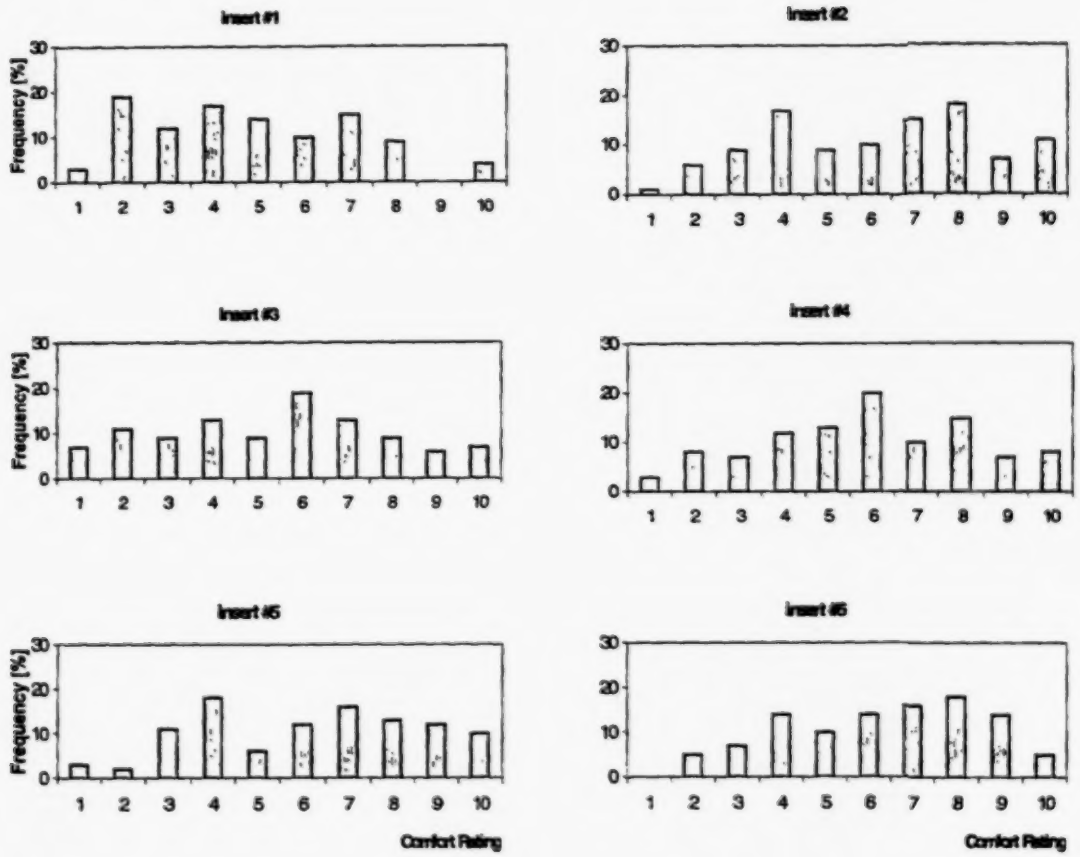


Figure 20. Distributions of comfort ratings for the six inserts used in this study (0 – not comfortable, 10 – very comfortable).

In general, all inserts significantly improved footwear comfort ($p < .001$). The average comfort rating for each insert was more than two points higher than the average comfort rating for the issued insert condition.

The insert with the highest comfort rating (insert #6) had a flat heel shape. It might have provided more space in the heel part of the combat boot compared to the inserts with a spherical heel shape. The insert with the lowest comfort rating (insert #1) was made of hard material and thus did not provide any additional cushioning. The majority of subjects disliked this material characteristic which is in agreement with Liu et al. (1998).

Table 7. Shape and material characteristics and average comfort ratings (0 – not comfortable, 10 – very comfortable) for the six different boot inserts and the issued insert condition.

No.	Shape		Hardness		Elasticity		Comfort Rating
	Arch	Heel	Heel	Forefoot	Heel	Forefoot	
1	high	spherical	hard	hard	elastic	elastic	4.2
2	high	spherical	soft	soft	elastic	elastic	5.6
3	high	spherical	soft	soft	viscous	viscous	4.8
4	high	spherical	soft	soft	viscous	elastic	5.3
5	low	spherical	soft	soft	viscous	elastic	5.6
6	high	flat	soft	soft	elastic	elastic	5.8
issued	-	-	-	-	-	-	1.8

Insert #5 (low arch) was rated second highest and was chosen as the most comfortable insert by the most subjects (n = 26). Inserts made of soft material with a high arch (#2, #3, #4, and #6) were the most comfortable inserts for groups of 17 to 19 subjects. Only five subjects rated insert #1 higher than all other insert conditions. Four subjects rated the issued insert condition higher than all inserts (Figure 21).

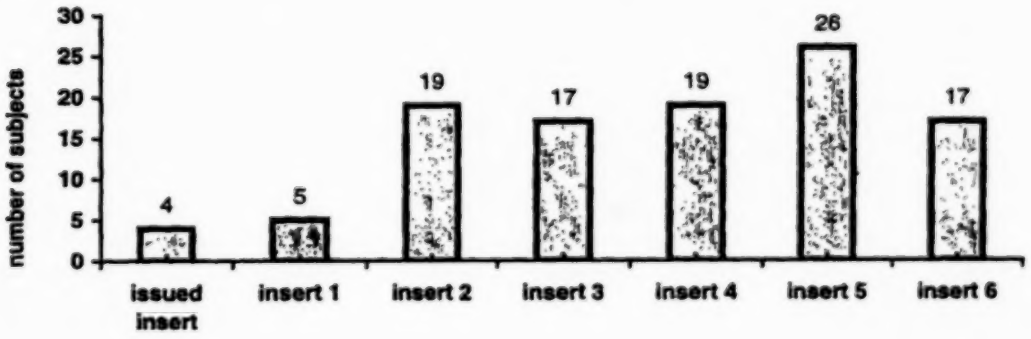


Figure 21. Subject distribution for highest comfort ratings.

The seven insert conditions (issued insert and inserts #1 to #6) were grouped into four subsets of insert conditions based on their average comfort ratings. The average comfort rating of each subset was significantly different from the average comfort ratings of all other subsets (student Newman Keuls test, $p < .001$) (Table 8). Inserts #2, #4, #5, and #6, which all belonged to the same subset of inserts (subset 4), were significantly more comfortable than the issued insert condition (subset 1) and inserts #1 and #3 (subset 2 and 3). There were no significant differences in the average comfort ratings within subset 4.

Table 8. The mean comfort values of seven insert conditions classified into four subsets based on mean comfort ratings.

	Subsets of insert conditions			
insert	**1**	**2**	**3**	**4**
issued	1.8			
#1		4.2		
#2				5.6
#3			4.8	
#4				5.3
#5				5.6
#6				5.8

The four subsets of insert conditions represented four levels of insert comfort, subset 1 being the lowest and subset 4 being the highest. The material characteristics related to the most comfortable subset (inserts #2, #4, #5, #6) were soft material in the heel region and soft and elastic material in the forefoot region. In contrast, the least comfortable inserts were made of hard material (insert #1) and of viscous material (insert #3) in the heel and the forefoot region. Thus, soft material in the heel region and soft and elastic material in the forefoot region are important features of inserts that improve footwear comfort.

A simple analysis was performed to obtain the number of inserts and their characteristics that improved comfort for the largest percentage of subjects (Table 9). A comfort rating more than two comfort points higher for an insert condition than the comfort rating for the issued insert condition was assumed to be equivalent to an improvement of footwear comfort.

Table 9. Number of subjects who experienced improved footwear comfort with inserts compared to the issued insert condition.

Insert number	Number of subjects [%]
#6	72.8
#5	72.8
#2	72.8
#4	68.9
#3	63.1
#1	52.4

72.8% of the subjects reported improved footwear comfort with insert #6. The percentage of subjects who experienced improved comfort was increased to 90.3% when adding inserts #5, #2,

and #4 (subset 4). Adding inserts #3 and #1 did not further increase the percentage of subjects with improved comfort. Thus, footwear comfort could be improved for a total of 90.3% of the subjects with only four inserts different in arch height, heel shape, and forefoot material (Table 10).

Table 10. Number of subjects who experienced improved footwear comfort with any insert of the insert combinations.

Insert number	Number of subjects [%]
6	72.8
6, 5	82.5
6, 5, 2	87.4
6, 5, 2, 4	90.3
6, 5, 2, 4, 3	90.3
6, 5, 2, 4, 3, 1	90.3

The relationship between insert comfort and foot characteristics

In the following, the most important subject characteristics for footwear comfort are specified. A more detailed description of the results is given for each insert pairing following this summary.

It became apparent that foot sensitivity and foot and leg geometry and alignment are independent factors for footwear comfort:

- Subjects with a low foot arch preferred an insert that gives way but also provides a certain amount of support and, therefore, liked the viscous insert and hard insert.
- A high foot arch provides support in itself. Thus, subjects with a high foot arch preferred a material that is soft, i.e. the soft insert and the elastic insert.

- Highly sensitive subjects don't need a high input signal. They preferred an insert that filters the input signal, i.e. the viscous insert and the soft insert.
- Less sensitive subjects may not be able to obtain sufficient information from the filtered impact input signal and, therefore, preferred the elastic insert.

In general, subjects that have a poor aligned skeleton or a low arch prefer viscous inserts whereas elastic inserts are more comfortable for subjects with a well aligned skeleton and a high arch. Table 11 shows the subject specific foot and leg characteristics that were relevant for insert comfort. Foot and leg characteristics that were not relevant for insert comfort were not included. The requirements for relevant foot and leg characteristics were outlined in the methods section above.

Table 11. Summary of the relationship between insert comfort and selected foot and leg characteristics. Only relevant foot and leg characteristics are included. Black = strong relationship; grey = weak relationship.

		soft #2	hard #1	viscous #3	elastic #2	viscous heel #2	elastic heel #4	spher. heel #2	Flat heel #6	high arch #4	low arch #5
Average comfort											
Arch height	high										
	low										
Heel angle	eversion										
	inversion										
Foref. fl. angle	large										
	small										
Achilles t. angle (subtalar)	poor										
	well										
Q-angle	poor										
	well										
Vibrat. Sens.	high										
	low										

Soft vs. hard elastic material (whole insert): insert #2 vs. insert #1

General result

In general, subjects preferred the soft over the hard insert. On average the soft insert was rated 1.4 points higher than the hard insert ($p < .001$).

Specific results

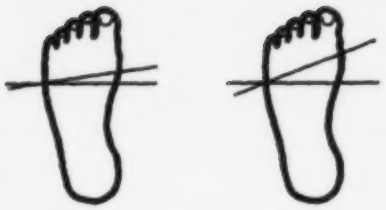
- ***Arch height:*** Subjects with a high foot arch preferred the soft over the hard insert (1.99 comfort point difference) and subjects with a low foot arch preferred the hard insert over the soft insert (0.79 comfort point difference) ($p = .006$). The low foot arch group was the only subgroup that preferred the hard insert. Both results were confirmed in the group comparison of the comfort rating between soft and hard ($p = .007$).

soft hard

Figure 22. Subjects with a high foot arch preferred the soft insert, subjects with a low foot arch preferred the hard insert.

- ***Leg alignment:*** Both subjects with small and large Q-angles preferred the soft insert over the hard insert. However, subjects with well aligned legs, i.e. small Q-angles rated the soft insert 2.84 comfort points higher than the hard insert whereas for subjects with poor aligned legs, i.e. large Q-angles, the difference in comfort rating was only 0.85 points ($p = .042$). This result was confirmed in the group comparison of the comfort rating between soft and hard ($p = .067$).

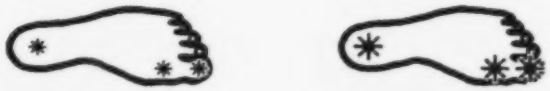
- ***Foot alignment:*** Subjects with a small forefoot flexion angle preferred the soft over the hard insert (2.09 comfort points difference). In contrast, subjects with a high forefoot flexion angle rated the soft only 0.51 points higher than the hard insert. However, the difference in comfort ratings between the two groups was significant ($p = .068$) (forefoot cushioning). This result was confirmed in the group comparison of the comfort rating between soft and hard.



soft no preference

Figure 23. Subjects with a small forefoot flexion angle preferred the soft insert and subjects with a large forefoot flexion angle had no preference for the soft or the hard insert.

- ***Foot sensitivity:*** Subjects with a low vibration sensitivity did not distinguish between the two inserts (difference in comfort rating < 0.50). However, subjects with a high vibration sensitivity at 30 Hz and 125 Hz at all locations except for the first metatarsal head at 125 Hz showed a strong preference for the soft over the hard insert (> 1.80 comfort points difference). The difference in comfort ratings between the two groups was significant ($p < .100$). Both results were confirmed in the comparison of the comfort rating between soft and hard ($p < .100$).



no preference soft

Figure 24. Less sensitive subjects had no preference for either soft or hard insert. Highly sensitive subjects at the heel, first metatarsal head, and hallux preferred the soft insert.

Synthesis

Most subjects preferred the soft over the hard insert. Several factors may play a role when choosing between a hard and a soft insert.

First, the foot arch height might play a role. A high foot arch provides support in itself. Thus, subjects with a high foot arch prefer the soft insert. In contrast, subjects with a low foot arch prefer an insert that provides a certain amount of support.

Second, the alignment of the leg and foot might play a role. Subjects with well aligned legs, i.e. small Q-angles, may have preferred soft inserts because the soft insert supported their natural leg alignment.

The strongest factor, as suggested by Liu et al. (1998), in the selection of soft over hard was the foot sensitivity. For those subjects who were very sensitive to vibration stimuli at 30 Hz and at 125 Hz, soft inserts were very important. Since soft inserts are assumed to reduce amplitude and frequency of the input signal to the body, i.e. impact loading, high sensitive subjects prefer soft inserts.

Table 12. Important factors for the comfort ratings of the soft and hard insert.

Soft vs. hard material (whole insert)			
General result	Soft preferred over hard insert		
Factors	**Comparison foot characteristics**	**Comparison comfort rating**	**In agreement with Liu et al.**
Arch height	High foot arch preferred soft	Subjects who preferred soft had a high foot arch	-
	Low foot arch preferred hard	Subjects who preferred hard had a low foot arch	-
Leg and foot alignment	Well aligned leg preferred soft	Subjects who preferred soft had well aligned leg	-
	Small forefoot flexion angle preferred soft		-
Foot sensitivity	Sensitive subjects (vibration 30 Hz and 125 Hz) preferred soft	Subjects who preferred soft were sensitive to vibration stimuli (30 Hz and 125 Hz)	yes

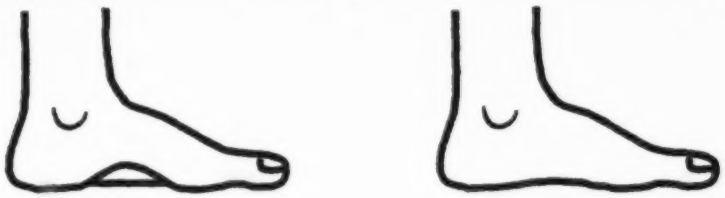
Viscous vs. elastic material (whole insert): insert #3 vs. insert #2

General results

In general, subjects preferred the elastic insert over the viscous insert. The average rating for the elastic insert was 0.75 comfort points higher than for the viscous insert ($p = .016$).

Specific results

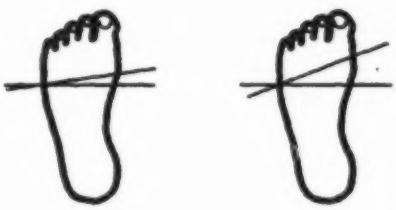
- ***Arch height:*** Subjects with a high foot arch preferred the elastic insert over the viscous (1.07 comfort points difference). In contrast, subjects with a low foot arch preferred the viscous over the elastic insert (1.07 comfort points difference) ($p = .040$). Both results were confirmed by the comparison of comfort ratings between viscous and elastic ($p = .011$).



elastic viscous

Figure 25. Subjects with a high foot arch preferred the elastic insert and subjects with a low foot arch preferred the viscous insert.

- ***Foot alignment:*** Subjects with a small forefoot flexion angle preferred the elastic insert over the viscous insert (0.84 comfort points difference). Subjects with a high forefoot flexion angle preferred the viscous over the elastic insert (1.25 comfort points difference) ($p = .071$). These results were not confirmed by the comparison of comfort ratings between viscous and elastic.



elastic viscous

Figure 26. Subjects with a small forefoot flexion angle preferred the elastic insert and subjects with a large forefoot flexion angle preferred the viscous insert.

- ***Foot sensitivity:*** Subjects with a low sensitivity (vibration at 125 Hz) at the hallux and at the heel preferred the elastic over the viscous insert (0.67 and 1.28 comfort points difference). Subjects with a high sensitivity (vibration at 125 Hz) at the hallux and at the heel preferred the viscous insert over the elastic insert (0.73 and 0.68 comfort points difference) ($p < .065$). Both results were not confirmed when the groups were compared based on comfort ratings of the two inserts.

elastic viscous

Figure 27. Less sensitive subjects at the heel and hallux preferred the elastic insert and highly sensitive subjects at the heel and hallux preferred the viscous insert.

Synthesis

In general, subjects preferred the elastic insert over the viscous insert. Different factors seemed to influence the comfort rating for the specific groups.

First, the foot arch height might have affected the comfort ratings. Viscous material absorbs shock better than elastic material. A high foot arch may be a better shock absorber than a low arch. Therefore, the viscous insert might have improved the shock absorbing shoe-foot system of subjects with a low foot arch and thus improved their comfort. In contrast, subjects with a high foot arch may not require the additional shock absorption. Liu et al. (1998) found that subjects with a high foot arch like the elastic heel insert over the viscous heel insert.

Foot alignment was an important factor. The combat boot fit better for subjects with a small forefoot flexion angle. However, the shape of the forefoot region of the boot did not match the shape of the foot of subjects with a large forefoot flexion angle. Thus, they preferred the viscous insert that provided more space.

Finally, the vibration sensitivity (125 Hz) was a factor in the comfort rating of elastic and viscous inserts. High sensitive subjects prefer an insert that filters out the input signal. This result is in agreement with Liu et al. (1998).

Table 13. Important factors for the comfort ratings of the viscous and the elastic insert.

Viscous vs. elastic material (whole insert)			
General result	Elastic preferred over viscous insert		
Factors	**Comparison foot characteristics**	**Comparison comfort rating**	**In agreement with Liu et al.**
Arch height	High foot arch preferred elastic	Subjects who preferred elastic had a high foot arch	-
	Low foot arch preferred viscous	Subjects who preferred viscous had a low foot arch	-
Foot alignment	Small forefoot flexion angle preferred elastic		-
	Large forefoot flexion angle preferred viscous		-
Foot sensitivity	Sensitive subjects (vibration 125 Hz) preferred viscous		yes
	Less sensitive subjects (vibration 125 Hz) preferred elastic		yes

Viscous vs. elastic heel material: insert #4 vs. insert #2

General results

In general there was little difference between the comfort rating of the viscous and the elastic heel insert. On average, the elastic heel insert was rated 0.26 comfort points higher than the viscous heel insert. The difference in comfort rating for these two inserts was not statistically significant. Both inserts were present in the subset of the most comfortable inserts.

Specific results

- ***Leg alignment:*** Subjects with a well aligned leg, i.e. a small Q-angle, preferred the elastic heel insert over the viscous heel insert (1.84 comfort point difference). In contrast, subjects with poorly aligned legs rated the elastic heel insert only 0.15 higher than the viscous heel insert. However, the difference between the comfort ratings of the two groups was statistically significant ($p = .039$). This result was not confirmed in the group comparison of the comfort rating between viscous and elastic.

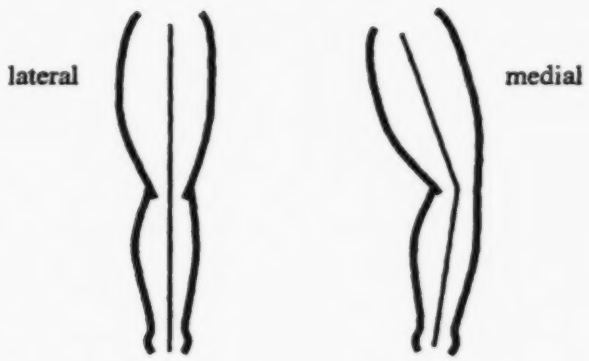


Figure 28. Subjects with a small Q-angle preferred the elastic heel insert and subjects with a large Q-angle had no preference for either elastic or viscous heel insert.

- ***Foot alignment:*** Subjects with a small forefoot flexion angle preferred the elastic over the viscous heel insert (0.85 comfort points difference). Subjects with large forefoot flexion angle rated the viscous heel insert higher than the elastic heel insert (1.11 comfort points difference) ($p = .043$). These results were not supported when grouping by comfort rating.

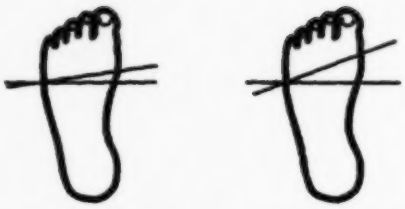


Figure 29. Subjects with a small forefoot flexion angle preferred the elastic heel insert and subjects with a large forefoot flexion angle preferred the viscous heel insert.

Synthesis

Although the difference in the comfort rating between the viscous and the elastic heel insert was small, the elastic heel insert was rated higher in average than the viscous heel insert. The following factors may play a role when choosing between elastic and viscous heel inserts.

The leg alignment played a role in the subjective assessment of comfort. Elastic material may support the natural movement more than viscous since latter material deforms over time and may restrict movement. Thus, subjects with well aligned legs may perceive movement restriction as resulting from viscous insert material as uncomfortable.

Foot alignment was an important factor. The combat boot fit better for subjects with a small forefoot flexion angle. However, the shape of the forefoot region of the boot did not match the shape of the foot of subjects with a large forefoot flexion angle. Therefore, their foot was shifted inside the boot. Thus, they preferred the viscous insert that provided more space in the heel region.

Table 14. Important factors for the comfort ratings of the viscous heel and the elastic heel insert.

Viscous vs. elastic heel material			
General result	Elastic heel preferred over viscous heel insert		
Factors	**Comparison foot characteristics**	**Comparison comfort rating**	**In agreement with Liu et al.**
Leg alignment	Well aligned preferred elastic		-
Foot alignment	Small forefoot flexion angle preferred elastic Large forefoot flexion angle preferred viscous		- -

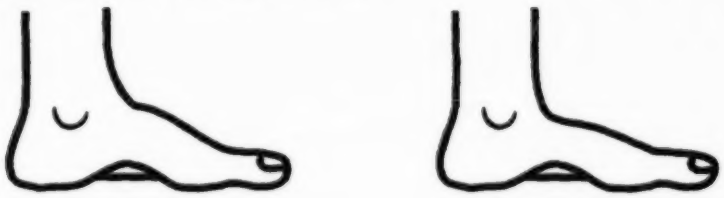
Elastic vs. viscous forefoot: insert #4 vs. insert #3

General results

In general the elastic forefoot insert was preferred over the viscous forefoot insert. On average, the elastic forefoot insert was rated 0.49 comfort points higher than the viscous forefoot insert ($p = .091$).

Specific results

- ***Dorsum height:*** Subjects with a high foot dorsum preferred the elastic forefoot over the viscous forefoot insert (1.40 comfort point difference). In contrast, subjects with a low foot dorsum rated the viscous forefoot insert 0.67 comfort points higher than the elastic forefoot insert ($p = .019$). Both results were confirmed in the group comparison of the comfort rating between elastic and viscous forefoot ($p = .094$).



elastic forefoot viscous forefoot

Figure 30. Subjects with a high foot dorsum preferred the elastic forefoot insert and subjects with a low foot dorsum preferred the viscous forefoot insert.

- ***Heel width:*** Subjects with a small W_{heel} rated the viscous forefoot insert 0.72 comfort points higher than the elastic forefoot insert. Subjects with wide heel, i.e. large heel width W_{heel}, preferred the elastic forefoot insert over the viscous forefoot insert (1.15 comfort point difference) ($p = .023$). These results were not supported when grouping by comfort rating.

viscous forefoot elastic forefoot

Figure 31. Subjects with a narrow heel preferred the viscous forefoot insert and subjects with a wide heel preferred the elastic forefoot insert.

Synthesis

In general, the subjects preferred the elastic forefoot insert over the viscous forefoot insert. Different factors seemed to influence the comfort rating for the specific groups.

Heel width played a role for the choice between the two inserts. Viscous material deforms over time and adapts to the shape of the foot. Subjects with a narrow heel may have preferred the viscous forefoot insert because this insert may have compensated for the poor fit in the heel region and thus the fit in the boot may have been improved.

It is unknown why dorsum height would have an influence on comfort perception of forefoot insert materials.

Table 15. Important factors for the comfort ratings of the elastic forefoot and the viscous forefoot insert.

Elastic vs. viscous forefoot material			
General result	Elastic forefoot preferred over viscous forefoot insert		
Factors	**Comparison foot characteristics**	**Comparison comfort rating**	**In agreement with Liu et al.**
Dorsum height	High foot dorsum preferred elastic forefoot Low foot dorsum preferred viscous forefoot	Subjects who preferred elastic forefoot had high foot dorsum Subjects who preferred viscous forefoot had low foot dorsum	- -
Heel width	Narrow heel preferred viscous forefoot Wide heel preferred elastic forefoot		- -

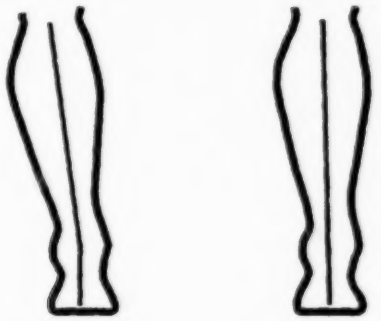
High vs. low arch: insert #4 vs. insert #5

General results

In general, the subjects preferred the low arch insert over the high arch insert. However, the difference between the rating of the two inserts was rather small and not significant. The low arch insert was rated 0.31 comfort points higher than the high arch insert. Both inserts are represent in the subset of the four most comfortable inserts.

Specific results

- ***Rearfoot alignment:*** Subjects with large Achilles tendon angle preferred the low arch insert (0.88 comfort points difference). Subjects with small Achilles tendon angles preferred the high arch insert over the low arch insert (0.64 comfort points difference) ($p = .045$). These results were not confirmed in the group comparison of the comfort rating between high and low arch.



low arch high arch

Figure 32. Subjects with a large Achilles tendon angle preferred the low arch insert and subjects with a small Achilles tendon angle preferred the high arch insert.

- ***Foot sensitivity:*** Less sensitive subjects (vibration, 125 Hz) at the hallux preferred the low arch insert over the high arch insert (1.68 comfort points difference). Sensitive subjects rated the high arch insert higher than the low arch insert (0.91 comfort points difference) ($p = .045$). These results were not supported by the difference between groups based on comfort rating.

low arch high arch

Figure 33. Less sensitive subjects at the hallux preferred the low arch insert and highly sensitive subjects preferred the high arch insert.

Synthesis

Most subjects preferred the low arch insert over the high arch insert. A combination of factors may have been the reason for choosing the low or the high arch insert.

The rearfoot alignment may have played a role. Subjects with a large Achilles tendon angle may undergo increased eversion movement throughout the gait cycle. A high arch insert would increase the pressure in the medial foot arch region. Thus, subjects with a large Achilles tendon angle prefer a low arch insert. Subjects with a small Achilles tendon angle may have a well aligned rearfoot throughout the gait cycle and therefore perceive the contact of insert and foot in the medial arch region as comfortable.

Sensitivity was an important factor for the comfort of the two inserts. Subjects with a very sensitive hallux may prefer the high arch insert because it may have decreased the pressure on the hallux. Wearing the high arch inserts the foot may have moved less in the boot and thus reduced the friction at the hallux. Less sensitive subjects may prefer the additional input information that is provided by a greater movement of the hallux.

Table 16. Important factors for the comfort ratings of the high arch and the low arch insert.

High vs. low arch			
General result	Low arch preferred over high arch insert		
Factors	**Comparison foot characteristics**	**Comparison comfort rating**	**In agreement with Liu et al.**
Rearfoot alignment	Large Achilles tendon angle preferred low arch		-
	Small Achilles tendon angle preferred high arch		-
Foot sensitivity	Sensitive (vibration 125 Hz) at hallux preferred high arch		no
	Less sensitive (vibration 125 Hz) at hallux preferred low arch		no

Spherical vs. flat heel shape (insert #2 vs. insert #6)

General results

In general, the flat heel shape was preferred over the spherical heel shape. However, the difference in comfort rating between the two inserts was only 0.22 points and not significant. Both inserts are in represent in the subset of the four most comfortable inserts.

Specific results

- ***Foot alignment:*** Subjects with small forefoot flexion angles rated the spherical heel shape only 0.24 comfort points higher than the flat heel shape. However, subjects with a high forefoot flexion angle preferred the flat heel over the spherical heel insert (1.40 comfort points difference) ($p = .082$). These results were not supported by the differences between the groups based on comfort ratings.

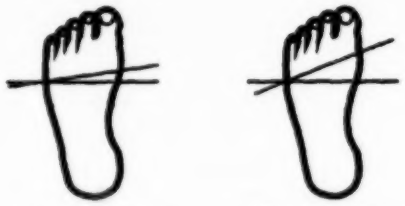


Figure 34. Subjects with a small forefoot flexion angle had no preference for either the flat heel shape or the spherical heel shape insert. Subjects with a large forefoot flexion angle preferred the flat heel shape.

- ***Rearfoot alignment:*** Subjects with an inverted rearfoot resting position preferred the spherical heel shape (0.99 comfort points difference) whereas subjects with an everted rearfoot resting position preferred the flat heel shape insert (1.77 comfort points difference) ($p = .023$). This result was confirmed in the group comparison of the comfort rating between spherical and flat heel shape ($p = .009$).

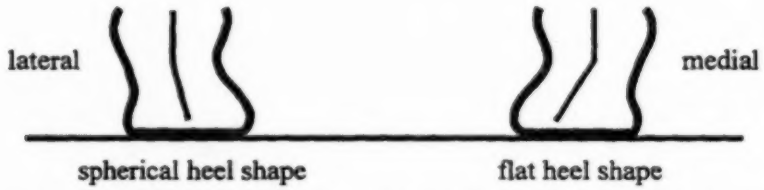


Figure 35. Subjects with an inverted rearfoot resting position preferred the spherical heel shape insert. Subjects with an everted rearfoot resting position preferred the flat heel shape insert.

- ***Foot sensitivity:*** Subjects less sensitive at the heel (vibration 30 Hz) and at the hallux (vibration 125 Hz) preferred the flat over the spherical heel (> 1.19 comfort points difference). In contrast, sensitive subjects rated the spherical heel insert only less than 0.20 comfort points higher than the flat heel insert. However, the difference between the two groups was statistically significant ($p < .090$). This result was not confirmed in the group comparison of the comfort rating between the spherical and flat heel.

flat heel sape no preference

Figure 36. Less sensitive subjects preferred the flat heel shape insert. Highly sensitive subjects had no preference for either the flat or the spherical heel shape insert.

Synthesis

Most subjects preferred the flat heel shape over the spherical heel shape. A combination of several factors may have been the reason for this choice.

Foot alignment was an important factor. The combat boot fit better for subjects with a small forefoot flexion angle. However, the shape of the forefoot region of the boot poorly matched the shape of the foot of subjects with a large forefoot flexion angle. Therefore, their foot was shifted inside the boot. Thus, they preferred the flat heel shape insert that provided more space in the heel region.

Rearfoot alignment was an important factor. In general, the eversion of subjects with everted rearfoot resting position was greater than the inversion of subjects with inverted rearfoot resting position. Thus, a spherical heel shape may increase the pressure in the medial heel region for the subjects in the everted rearfoot group and thus be uncomfortable. Since the inversion of subjects in the inverted rearfoot group was rather small, the spherical heel shape may have provided a snug fit which may have been perceived as comfortable.

Table 17. Important factors for the comfort ratings for the spherical and the flat heel shape insert.

Spherical vs. flat heel shape			
General result	Flat heel shape preferred over spherical heel shape insert		
Factors	**Comparison foot characteristics**	**Comparison comfort rating**	**In agreement with Liu et al.**
Foot alignment	Abducted forefoot preferred flat heel shape		-
Rearfoot alignment	Inverted preferred spherical heel shape	Subjects who preferred spherical heel shape had inverted rearfoot resting position	-
	Everted preferred flat heel shape	Subjects who preferred flat heel shape had everted rearfoot resting position	-
Foot sensitivity	Less sensitive subjects (vibration 30 Hz) at heel and (vibration 125 Hz) at hallux preferred flat heel shape		no

Injury assessment

Only five percent of all subjects returned a completed logbook. However, no injuries were reported. Thus, the following results are based on information of 78 subjects, 45 of the control group and 34 of the insert group, who returned a completed injury questionnaire at the completion of the 4 month wear period. The majority of subjects had not seen a physician during the four month period. From the four subjects who reported a visit to a physician, two suffered from an acute injury such as an ankle or knee sprain that occurred during sports activities when regular sport shoes had been worn. Therefore, these two injuries were excluded from this part of this investigation. The other two injury reports were stress fractures at the foot and thus related to the footwear worn during military activities. Therefore, these two cases were included in this study. In the following, pain, stress fractures, and blisters are discussed separately. Pain and stress fractures are grouped based on the location of their incidence.

Overall injuries and severity

A higher percentage of subjects in the insert group reported injuries compared to subjects in the control group (based on returned questionnaires) (Table 18).

Table 18. Injuries reported on returned questionnaires per group.

	Control group (n = 45)		Insert group (n = 34)	
	#	%	#	%
no injuries	28	62.2	19	55.9
injuries	17	37.8	15	44.1

However, the numbers of subjects with stress fractures or pain were lower for the insert compared to the control group. 66.7% of the injured subjects in the insert group reported pain compared to 76.5% of the injured subjects in the control group. None of the subjects in the insert group had a stress fracture compared to 11.8% of the injured subjects in the control group. The number of hot spots and blisters was 22.4% higher for the insert group (40.0%) compared to the control group (17.6%) (Table 19). Some subjects reported that their feet had stuck to the inserts. Since the surface of the inserts was rubber like, the socks may have stuck more to the insert than they would to a regular boot. This may have caused higher friction between the sock and the foot and thus led to the reported blisters and hot spots.

Table 19. Distribution of specific injuries reported on returned questionnaires that reported injuries.

	Control group (n = 17)		Insert group (n = 15)	
Severity of injuries	#	%	#	%
Hot spots/blisters	3	17.6	6	40.0
Stress fractures	2	11.8	0	0.0
Pain	13	76.5	10	66.7

Stress fracture and pain locations

The main locations for stress fractures and pain for the insert and the control group were the foot, the knee and the lower back regions (Figure 37). The number of stress fractures and pain at any location was between 5.1% and 38.8% lower for the insert compared to the control group (based on returned questionnaires). The greatest and also statistically significant difference in stress fracture or pain incidence occurred at the foot. Ten subjects in the control group (58.8%) suffered a stress fracture or pain at the foot as opposed to only 3 subjects in the insert group (20.0%) ($p = .036$).

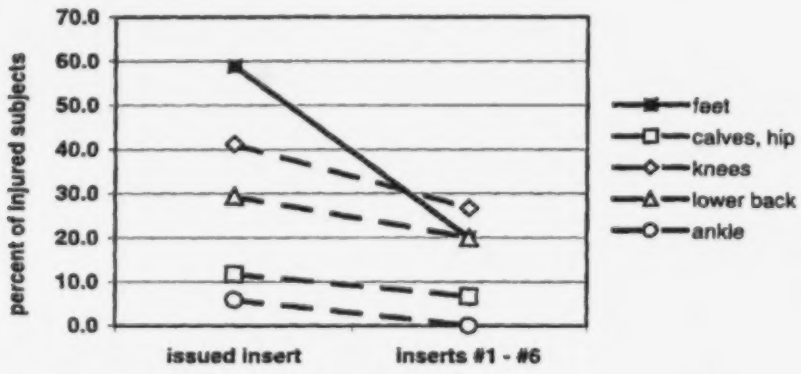


Figure 37. Percent of injured subjects for different injury locations. Solid line = significant difference ($p = .036$).

Injuries and inserts

Each subject in the insert group had chosen his/her most comfortable insert and wore this insert during the time of injury assessment. Figure 38 illustrates the percentage of injured subjects for each chosen insert (based on returned questionnaire).

The groups of subjects, who chose inserts #1, #2, or #3 as their most comfortable insert, were very small (2, 5, and 3 subjects). Thus, meaningful information could only be obtained for inserts #4, #5, and #6. Insert #5, which was chosen as the most comfortable by the largest group of subjects (see comfort results), also led to the smallest number of subjects that experienced any injury. This may be an indication of a positive relationship between injury incidence and boot insert comfort.

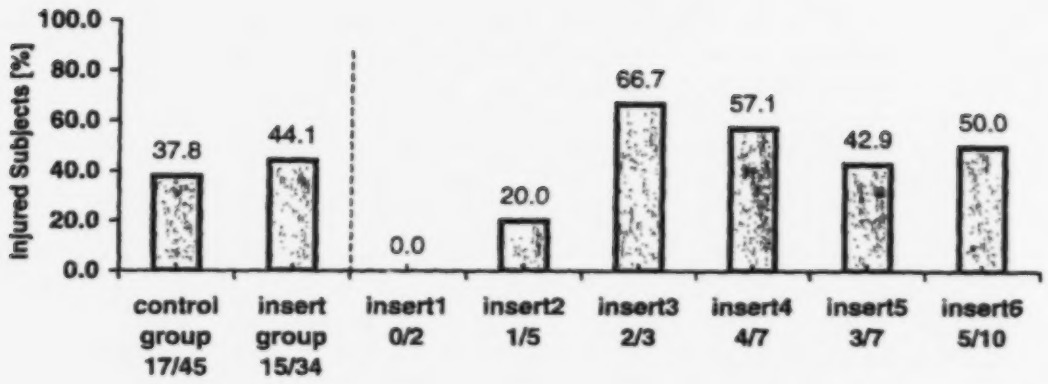


Figure 38. Percentage of injured subjects for control and insert group and for each chosen insert based on returned questionnaire.

Performance testing

The subjects showed a large variation in their maximum oxygen consumption (Table 20). The results of the performance tests are illustrated in Figure 39. The differences between the two tested conditions, comfortable insert vs. issued insert, were rather small for all subjects. The hypothesis that a comfortable insert would reduce the oxygen consumption and, therefore, energy expenditure was not supported. However, this data is based on a limited sample size.

Table 20. Maximum oxygen consumption and difference in oxygen consumption between the two tested conditions.

Subject ID	$\dot{V}O_{2,max}$ [ml/kg/min]	$\dot{V}O_{2,insert} - \dot{V}O_{2,issued\ insert}$ [ml/kg/min]	$\dot{V}O_{2,insert} - \dot{V}O_{2,issued\ insert}$ [%]
41	38.1	-0.63	-2.7
22	42.8	-0.56	-2.0
5	23.1	-0.17	-0.7
3	37.6	-0.16	-0.7
1	34.8	-0.01	0.0
108	50.8	0.04	0.1
34	37.5	0.15	0.5
37	41.4	0.24	0.9

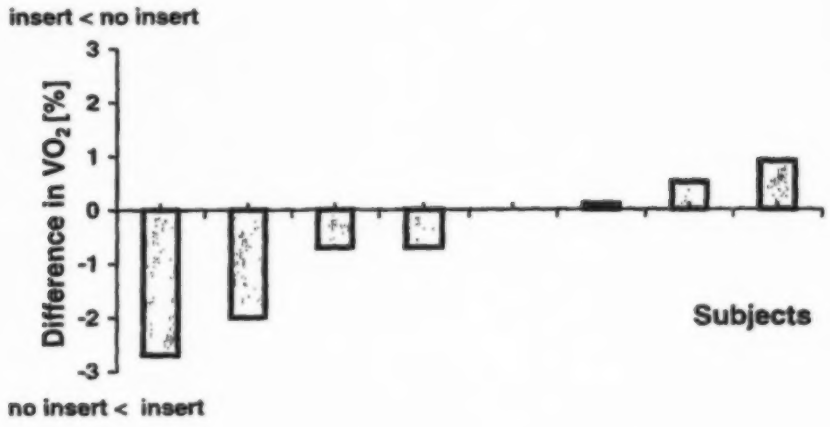


Figure 39. Difference in oxygen consumption between the comfortable insert and issued insert condition in percent. Positive values correspond to a higher oxygen consumption for the insert condition compared to the issued insert condition. Negative values correspond to a higher oxygen consumption for the issued insert condition compared to the insert condition.

Clement et al. (1982) found no significant difference in oxygen consumption in running with an orthotic compared to a non-orthotic condition and explained these results with a high variability between subjects. However, it has also been shown that orthotic conditions increase the amount of energy required in running compared to a non-orthotic condition (Hayes et al., 1983; Burkett et al, 1985). Thus, it remains unclear how inserts and orthotics affect running economy. The question if specific subject characteristics were related to the difference in oxygen consumption between the comfortable insert condition and the issued insert condition could not be answered due to the small number of subjects tested. The regular military schedule did not allow for a larger subject group. Thus, further research needs to be conducted to address this question.

SUMMARY

Comfort results

All insert conditions led to a significant increase in comfort rating compared the issued insert condition. Only 4 out of 103 subjects rated the issued insert condition as the most comfortable. The inserts with the highest comfort ratings were composed of soft material in the heel region and soft and elastic material in the forefoot region. In contrast, the least comfortable inserts were made of hard material in the heel and forefoot region and/or a viscous material in the forefoot region. These results are similar to the results found in the initial study. Only four different inserts were necessary to substantially increase the comfort rating (greater than two comfort points) for ninety percent of the individuals. Thus, it appears that only a small number of inserts are necessary to satisfy a large portion of the military population.

Specific insert results

It became apparent that foot sensitivity and foot and leg geometry and alignment are independent factors for footwear comfort:

- Subjects with a low foot arch preferred an insert that gives way but also provides a certain amount of support and, therefore, liked the viscous insert and hard insert.
- A high foot arch provides support in itself. Thus, subjects with a high foot arch preferred a material that is soft, i.e. the soft insert and the elastic insert.

- Highly sensitive subjects do not need a high input signal. They preferred an insert that filters the input signal, i.e. the viscous insert and the soft insert.
- Less sensitive subjects may not be able to obtain sufficient information from the filtered impact input signal and, therefore, preferred the elastic insert.

In general, subjects that have a poor aligned skeleton or a low arch prefer viscous inserts whereas elastic inserts are more comfortable for subjects with a well aligned skeleton and a high arch.

Injury results

Overall, 40.5% of the subjects who provided injury data had an injury. Injuries were defined as any pain, hot spots/blisters, and stress fractures. There were no significant differences in the overall number of injuries between the insert and the control group. However, the number of subjects with pain and stress fractures were lower for the insert compared to the control group. There was a significant decrease in pain and stress fractures in the feet of the subjects using inserts. Thus, it appears that inserts may have a positive effect in reducing more severe injuries in military personnel. The inserts did cause an increase in the number of blisters/hot spots encountered by the subjects. The particular inserts used appeared to have a rather high friction coefficient which could have lead to the increased number of blisters. Thus the surface characteristics of any inserts should be carefully considered before implemented.

Performance Results

There were no significant differences in the oxygen consumption (energy expenditure) of subjects when marching with the test inserts or with the issued inserts. Previous studies have shown increased oxygen consumption with inserts, primarily due to the additional energy required to accelerate the added mass. This was not found in this study, and it may be that the positive effects (e.g. improved comfort) of the insert condition offset the negative effect of the added mass. However, the information with respect to performance should be interpreted with caution as this data is based on a limited sample size of only eight subjects.

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APPENDIX A

Comfort questionnaire used in this study. Subjects in insert group filled out one questionnaire per insert condition.

Insert #_

How would you rate the forefoot cushioning?	very soft	very hard
	very comfortable	not comfortable
How would you rate the heel cushioning?	very hard	very soft
	very comfortable	not comfortable
How would you rate the arch height?	very high	very low
	very comfortable	not comfortable
How would you rate the heel cup fit?	very loose	very tight
	very comfortable	not comfortable
How would you rate the shoe heel width?	very wide	very narrow
	very comfortable	not comfortable
How would you rate the shoe forefoot width?	very narrow	very wide
	very comfortable	not comfortable
How would you rate the shoe length?	very long	very short
	very comfortable	not comfortable
How would you rate the INSERT overall?	very comfortable	not comfortable

Comments:

APPENDIX B
Injury questionnaire. Each subject received a questionnaire after the completion of the 4 month wear period.

COMBAT BOOT INSERT TRIAL
INJURY QUESTIONNAIRE

Name, Rank, Initials _____ Coy_____

Information about the logbook

☐ I lost my logbook

☐ I still have my logbook and it is enclosed with this questionnaire

☐ Other (Please specify)_____

For the evaluation of all collected data it is necessary to get information about any lower extremity injury (lower back, legs, knees, feet, etc.) you had in the time period June-October 1999.

☐ I have seen a physician (or reported to the UMS) concerning an injury or pain in my legs or feet. I agree that my Medical Records can be used for research purposes. All information will be kept CONFIDENTIAL and ANONYMOUS.

Signature_____ Date_____

☐ I have not seen a physician (or reported to the UMS) in the past four months concerning an injury or pain in my legs or feet.

Please list the injuries and pain that you experience in your lower extremities in the past four months (insert or non-insert group).

Part of the body i.e. foot, knee, hip, lower back	**Frequency of injury**	**Description of injury or pain**

APPENDIX C

Instructions for the Medical Assessment Logbook

The **Medical Assessment Logbook** is a part of the **Combat Boot Insert Trial** in which you are a participant. Please read the following instructions carefully.

1. Please print your name including first initial, your rank and company as well as your birthday on the first page of your personal logbook.

The following pages of your logbook all show the same text on the front and sketches on the back. Please fill out one page per week.

2. Please print the date of each day in the according spaces.
   - **Running** please write the running distance you ran on this particular day.
   - **Marches** please write the marching distance you did on this particular day.
   - **Others** please specify other physical activities you did on this particular day.

3. Please flip the page over and you will find sketches of a right and left leg and foot. Please mark the places where you felt any pain or discomfort in this particular week and make a short note to characterize this pain or discomfort.

Page 1

Week 1

Mon . ./. . .99 Running . . . .km
Marches ..... km Others. ....
. . ..

Tue ... . .. /. . .99 Running.... . ... km
Marches . .. . . .km Others..... .. ..
....

Wed ... /.. ....99 Running .. .. km
Marches .. . .km Others . .. .
.. ..

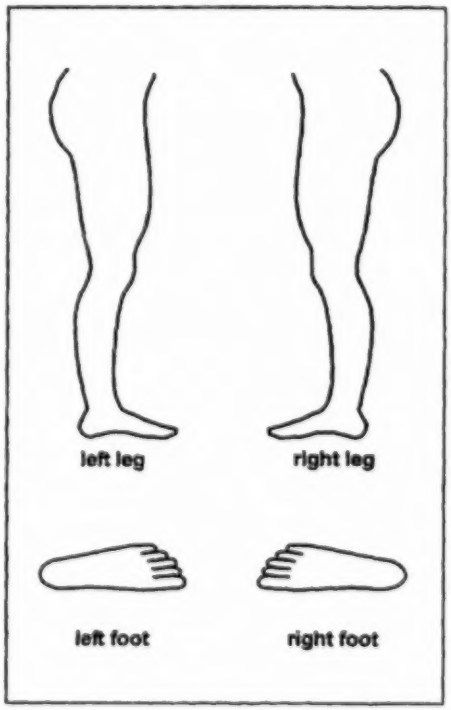
Thu .. .../.....99 Running.. ..... km
Marches . ..... km Others. . ...
. ...

Fri .. . . / ...99 Running.....km
Marches ....km Others..... ....
. . . .

Sat .. .../..... 99 Running... ... km
Marches ..... . .km Others.. ....
... .

Sun ..../..... 99 Running.... .... .km
Marches . ..... km Others .. ..
.. . .

Page 2



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14. ABSTRACT

(U) Army personnel are often required to spend significant amounts of time executing their tasks while wearing the same footwear. The importance of appropriate footwear for this population is obvious. However, what is considered appropriate footwear for one individual may not be appropriate for another individual. The fact that the majority of the military population is issued identical footwear would suggest that at least some individuals do not have appropriate footwear. Unfortunately, the guidelines for determining an appropriate boot for an individual are not well determined. Ultimately, these guidelines should be used to prescribe appropriate footwear to specific individuals.

As a first step in understanding these guidelines, an initial study was performed to determine the anthropometric and sensory factors which may predict the short term reaction of the foot to a set of selected shoe-insert constructions. The study found that changes in insert properties elicited substantial changes in comfort ratings of a group of 106 university students. The comfort ratings depended on specific insert characteristics as well as lower extremity characteristics such as foot sensitivity and leg alignment. This current study was the second step in understanding these guidelines and was performed as a follow up study to identify similar characteristics using a military population and to determine the influence of inserts on injuries and performance.

The purposes of this study were to determine:
a) lower extremity anthropometric and sensory factors which predict the comfort of selected boot-insert constructions in a military population and
b) the influence on boot inserts on lower extremity injuries and performance of a military population executing military tasks.

A total of 206 military personnel from the Edmonton Garrison volunteered for this study. The subjects were split into two groups of 103 subjects, an insert group and a control group. Foot shape, leg characteristics, and foot sensitivity measurements were taken from all 206 subjects. Subjects in the insert group chose the most comfortable insert from a set of six boot inserts different in shape and material. The foot measurements and comfort assessments were conducted at the PPCLI unit in Edmonton, Alberta. Subjects then wore the selected inserts for a period of four months. During these four months, subjects in both groups (insert group and control group) reported any pain or injuries they experienced. At the end of four months, eight subjects from the insert group performed oxygen consumption tests with and without their chosen inserts in their combat boots. The oxygen consumption tests were performed at the exercise physiology laboratory at the University of Alberta, Edmonton.

Comfort results

All insert conditions led to a significant increase in comfort rating compared to the issued insert condition. Only 4 of 103 subjects rated the issued insert condition as the most comfortable. The inserts with the highest comfort ratings were composed of soft material in the heel region and soft and elastic material in the forefoot region. In contrast, the least comfortable inserts were made of hard material in the heel and forefoot region and/or viscous material in the forefoot region. These results are similar to the results found in the initial study. Only four different inserts were necessary to substantially increase the comfort rating (greater than two comfort points) for ninety percent of the individuals. Thus, it appears that only a small number of inserts are necessary to satisfy a large portion of the military population.

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- Subjects with a low foot arch preferred an insert that gives way but also provides a certain amount of support and, therefore, liked the viscous insert and hard insert.
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- Less sensitive subjects may not be able to obtain sufficient information from the filtered impact input signal and, therefore, preferred the elastic insert.

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Overall, 40.5% of the subjects who provided injury data had an injury. Injuries were defined as any pain, hot spots/blisters, and stress fractures. There were no significant differences in the overall number of injuries between the insert and the control group. However, the number of subjects with pain and stress fractures were lower for the insert compared to the control group. There was a significant decrease in pain and stress fractures in the feet of the subjects using inserts. Thus, it appears that inserts may have a positive effect in reducing more severe injuries in military personnel. The inserts did cause an increase in the number of blisters/hot spots encountered by the subjects. The particular inserts used appeared to have a rather high friction coefficient which could have lead to the increased number of blisters. Thus the surface characteristics of any inserts should be carefully considered before implemented.

Performance Results

There were no significant differences in the oxygen consumption (energy expenditure) of subjects when marching with the test inserts or with the issued inserts. Previous studies have shown increased oxygen consumption with inserts, primarily due to the additional energy required to accelerate the added mass. This was not found in this study, and it may be that the positive effects (e.g. improved comfort) of the insert condition offset the negative effect of the added mass. However, the information with respect to performance should be interpreted with caution as this data is based on a limited sample size of only eight subjects.

Speculation-Concepts

It is speculated that the majority of the military population can be appropriately served with only four different types of inserts. In general these inserts should be soft and have an elastic forefoot. Options of a low or high arch, a flat or spherical heel and a viscous or elastic heel region should also be available.

The speculation that subjects with a poor alignment of the skeleton (heel, subtalar joint, tibial torsion, Q-angle) are best served with a soft and viscous insert was supported. Subjects with poor skeletal alignment do not want anything resisting their foot movement and, thus, prefer soft and viscous materials.

Similar to the results that were found previously, subjects that are highly sensitive prefer soft and viscous materials. Subjects that have a low sensitivity prefer hard elastic materials. These speculations can be supported by functional considerations. Subjects who are highly sensitive do not need extra input signals. However, subjects who are not highly sensitive may need strong input signals produced by the hard elastic materials.

It is speculated that the use of inserts will result in reduced lower extremity injuries. It will be important to have appropriate surface characteristics to avoid blisters, but if correctly constructed, the potential to reduce more severe injuries exists. The use of inserts is also speculated to have little or no effect on performance.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) combat boots; inserts; comfort; military; anthropometry; sensory factors; foot; leg; lower extremity; field trial; oxygen consumption; injury data; performance